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Michael Fish's famous 1987 'no hurricane' prediction was technically correct → p63

WELCOME

I never really 'got' gravity at school. I knew gravity was what made apples fall to the ground and planets loop around the Sun, but I could never satisfactorily get my head around how it actually worked. It wasn't until university, when I walked into a classroom with nylon stretched out between some tables like a badly made trampoline, that I really understood. The nylon, my friend explained, was space-time, the fabric of the Universe. The weight in the centre, stretching the fabric towards the floor, was the Sun. This was what huge objects like stars did to space-time: they warped it, only in three dimensions rather than just two. Throw some marbles in and they became recognisable as small planets orbiting a large sun. Throw in dozens, and you soon saw why solar systems tend to orbit stars in one direction. Physicists will be familiar with the demonstration I'm talking about, but luckily for everyone else, I recently came across a much better recreation of it on YouTube – search for 'gravity visualized' (they're American) to see it for yourself.

My point is, gravity is an elusive concept. The nylon analogy demonstrates Einstein's take on gravity, the General Theory of Relativity, but unfortunately these neat, simple 'rules' can't be reconciled with quantum mechanics, the other cornerstone of modern physics. It also leaves us with some big questions about the way our Universe works, such as why it seems to be expanding at an ever increasing speed. But one theoretical physicist, Erik Verlinde thinks he might have a solution – and it's one that could rewrite the laws of physics as we know them. Turn to p40 to find out more…

Enjoy the issue!

Daniel Bennett, Editor

IN THIS ISSUE

DUNCAN GEERE
Thirty years on from the Great Storm, Duncan asks why we failed to predict it, and why we still have trouble forecasting the weather today. → p61

DINSA SACHAN
Dinsa is a science and culture journalist based in New Delhi. This month she wonders: "Will artificial intelligence ever be able to create art?" → p73

HELEN THOMSON
As the author of an upcoming book on the human brain, science writer Helen is the ideal person to unravel the mysteries of memory. → p66

COVER: MAGIC TORCH

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Chin dimples are a dominant genetic trait → p101

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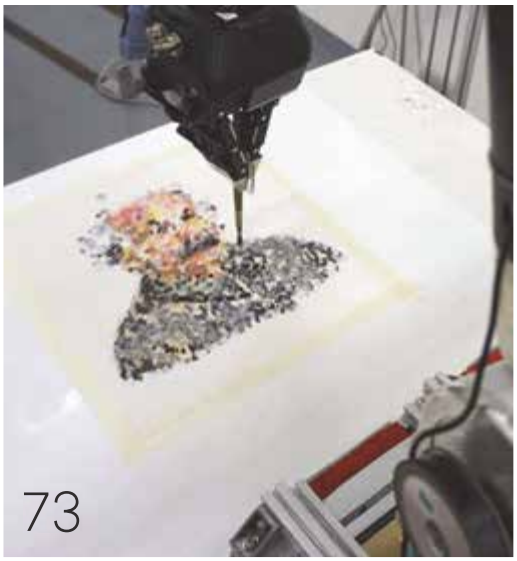

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Martian snow

NORTHERN HEMISPHERE,
MARS

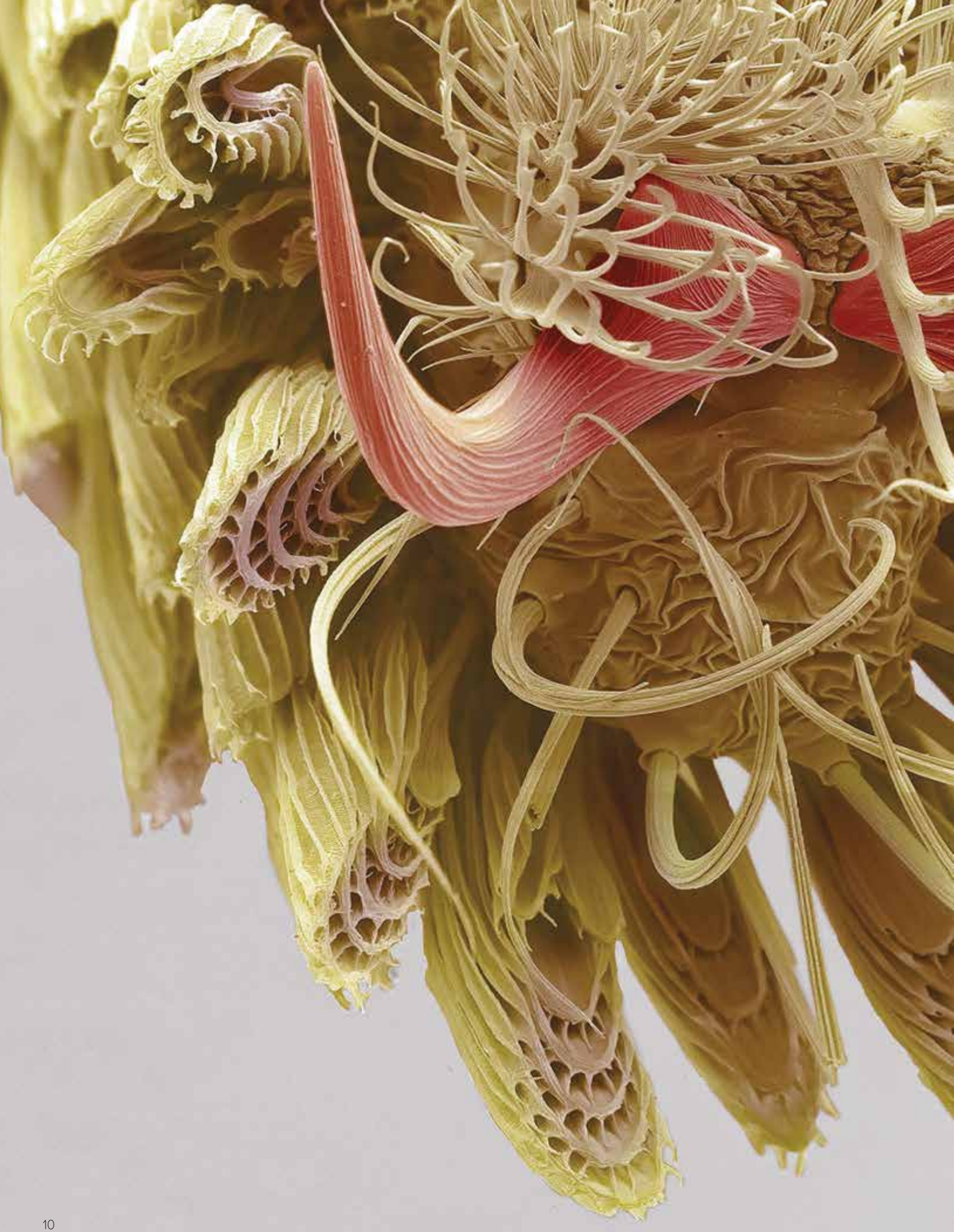
We're dreaming of a white Christmas... on Mars. These sand dunes in the planet's northern hemisphere have been dusted with an unusual kind of snow, formed not from water but from carbon dioxide (CO_2). Better known as dry ice, it appears during the Martian winter when temperatures drop and atmospheric CO_2 freezes, forming ice on the planet's surface or falling from the clouds as snow.

As the Sun reappears in spring, the pristine covering begins to crack, releasing gaseous carbon dioxide that carries dark sand up from the ground below. The result is these beautiful patterns, captured last May by the High Resolution Imaging Science Experiment (HiRISE) camera on NASA's Mars Reconnaissance Orbiter.

"Frozen CO_2 is common on Mars," explains Dr Candice Hansen, senior scientist at the Planetary Science Institute in Tucson, Arizona. "A seasonal polar cap made of dry ice forms each year at the north and south poles, and we even get patchy deposits close to the equator."

We won't be getting any here on Earth, though. CO_2 requires temperatures of -78.5°C to freeze, so keep your fingers crossed for normal snow instead.

PHOTO: NASA



EYE OPENER

Strange things are afoot

This alien-like appendage is the foot, or tarsus, of a mosquito. While mozzies' legs may not look like much to the naked eye, this scanning electron micrograph image was taken at 800 times magnification to reveal the tarsus' intricate microstructure. Incredibly, each of the bizarre-looking formations serves a particular purpose.

"The two tarsal claws that are clearly visible allow the mosquito to grip onto most surfaces, like walls, plants or your leg. The surrounding structures, the 'socks', act as buffers, allowing the mosquito to land gently and accurately on all manner of surfaces," says BBC presenter and entomologist Prof Adam Hart. "It isn't just about physical prowess – the hairs on the feet also act as sensory structures, effectively allowing them to taste with their feet!"

The image is one of the top 100 selected to tour the UK as part of the Royal Photographic Society's International Images for Science. Visit **rps-science.org** for more details.

PHOTO: STEVE GSCHMEISSNER/RPS

REPLY

Your opinions on science, technology and *BBC Focus*

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The true nature of OCD is understood by very few people

MESSAGE OF THE MONTH

INVISIBLE ILLNESS

I would like to commend James Lloyd for his article about his personal battle with OCD (October, p60). I myself struggled with 'intrusive thoughts' similar to those described by James (internal rather than physically visible OCD) for four to five years before being diagnosed with anxiety back in 2005. It led to depression and the worse period of my life to date. However, back then, even after being diagnosed with anxiety, I had never heard the term 'intrusive thoughts' and until reading James' article thought they were just a side effect of the anxiety.

Everything James describes is exactly what I experienced and I would never have thought to class it as OCD. It really does show that there is still a lot that needs to be done to raise awareness of the many forms OCD can take. Now, 12 years on, all is well in my brain… and I wish James the best of luck with his recovery.

Jean-Denis Hibbitt, Weymouth

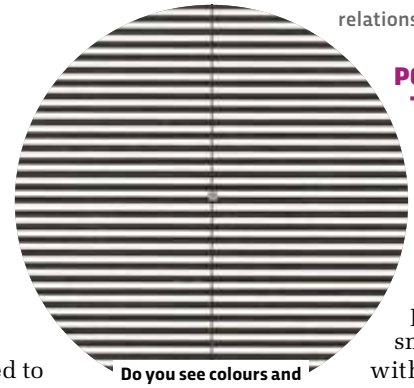
I've heard so many stories of people suffering for years, even decades, not knowing that they have an illness which can be diagnosed and treated. I think it's partly stigma around the intrusive thoughts themselves, but mostly a general misunderstanding of what OCD really is. Writing the article was one of the hardest things I've ever done, but hopefully it can go a small way to redressing the balance. Thanks for your feedback! ***– James Lloyd, editorial assistant***

BETWEEN THE LINES

I've always watched lines, letters and words jiggle and dance on the page as I've read, an inconvenience which slows me down. So I loved the pattern glare test included with your article on out of body experiences (September, p70).

I could see lightning bolts in the pattern, pinks, blues and yellows swirled around, the shape started to look 3D and the lines merged into grey or changed thickness as I tried to focus on the central dot. I'd always seen this as a trait of my dyslexia, but the idea that it could be due to cortical hyper-excitability seems much more glamorous! Is there a link between dyslexia and cortical hyper-excitability and/or OBEs?

Amy Rouse, Derby



Do you see colours and motion, or just regular black and white lines?

There *is* thought to be a link between the two, but the exact nature of the relationship isn't clear. ***– Ed***

POWER TO THE PEOPLE

Dinorwig power station in Wales is a gravity-powered energy storage unit. Surely the same principle, on a smaller scale and with more units, could contribute to the need to store energy, especially as such units could be built at a fraction of the cost of a Dinorwig-type facility?

PHOTOS: SAM FALCONER/DEBUT ART, VOLOCOPTER

I have no idea how many disused vertical mine shafts there are in the UK, but I would guess that there quite a few, and many of these will be well over a mile deep. A weight on a cable is lowered to the bottom, at off-peak times it is raised, and on demand the descending weight drives the generator. Very low-maintenance, low-staffing and eco-friendly… I am aware it may not be a new idea, but simple is best!

Douglas Scarff, via email

We already have solutions like this dotted around the country, including one approach which pumps water up to reservoirs at the top of hills and releases it through turbines during periods of peak energy demand. The nature of energy provided by fossil fuels mean we don't currently tend to rely on these systems that much, but as renewable energy becomes prevalent we could indeed see many more stations like this, including large batteries in the home, installed around Europe. ***– Ed***

A FLIGHT OF FANCY?

I read with interest the article on the Volocopter (October, p30). As depicted, it looks interesting and capable of filling a niche, but on further examination it appears fatally flawed. What happens if the engine stops? Unlike in the helicopter, which can auto-rotate down safely in the event of engine failure, the Volocopter appears to have no provision for such a situation. The small rotors might rotate during a descent without power, but they could not provide enough life to allow the machine to make a controlled descent and a safe landing. Perhaps fewer and larger rotors might provide the solution, but then we are turning it back into a helicopter!

John Fay, Somerset
(author of *The Helicopter*)

Good question, John – watch this space! We've been in touch with the Volocopter's creators and will include their response in a future issue. ***– Ed***

The Volocopter autonomous air taxi could soon become a reality – but how safe is it, asks John Fay?

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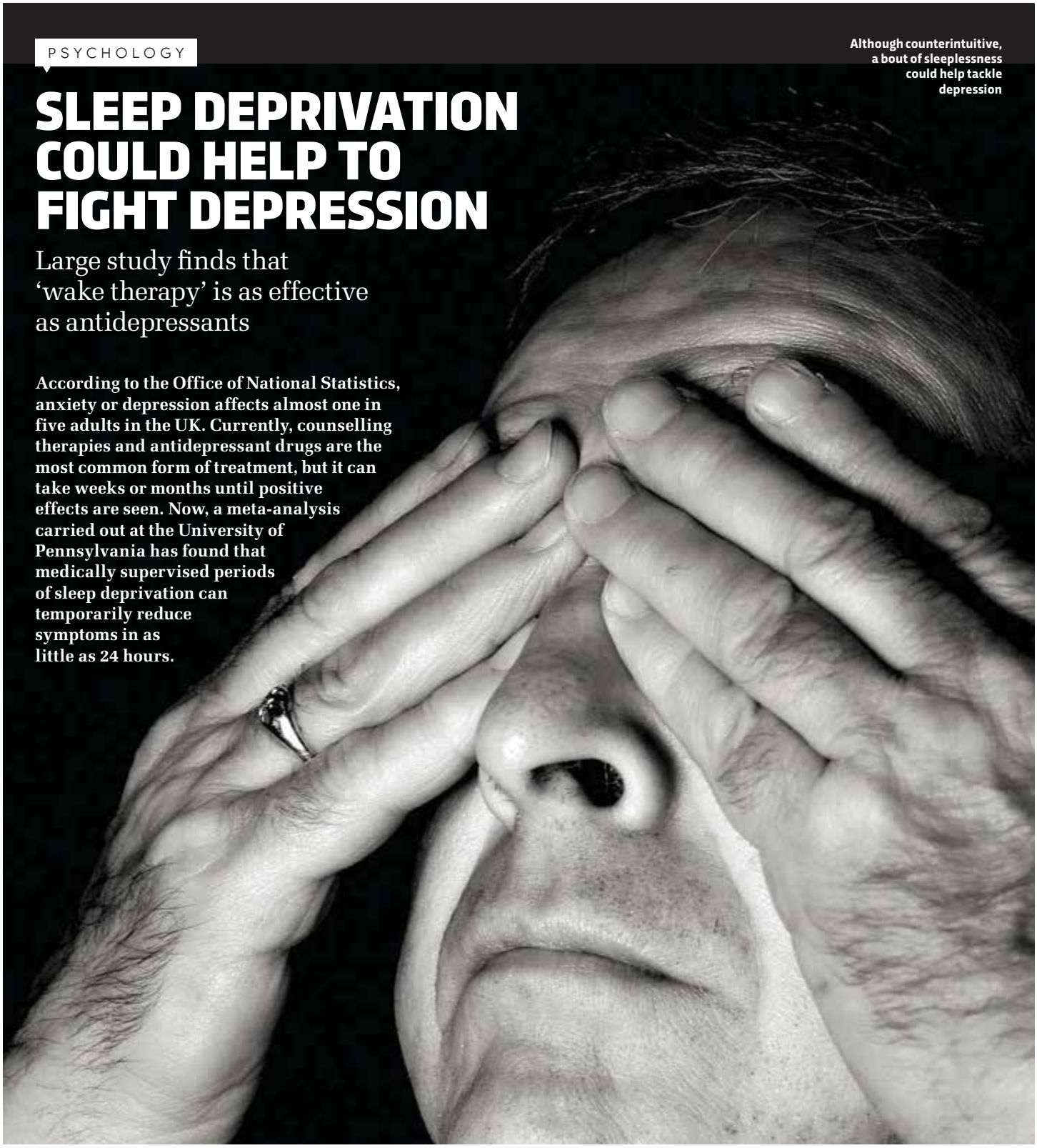
PSYCHOLOGY

SLEEP DEPRIVATION COULD HELP TO FIGHT DEPRESSION

Large study finds that 'wake therapy' is as effective as antidepressants

According to the Office of National Statistics, anxiety or depression affects almost one in five adults in the UK. Currently, counselling therapies and antidepressant drugs are the most common form of treatment, but it can take weeks or months until positive effects are seen. Now, a meta-analysis carried out at the University of Pennsylvania has found that medically supervised periods of sleep deprivation can temporarily reduce symptoms in as little as 24 hours.



Although counterintuitive, a bout of sleeplessness could help tackle depression

PHOTO: GETTY

Sleep deprivation therapies could offer new hope to sufferers

It's been known for some time that sleep deprivation has potential antidepressive effects, but exactly how effective it is and how it works has remained a mystery. To investigate this further, the team compiled data from a carefully selected group of 66 studies dating back some 36 years, selecting these from an initial 'long list' of more than 2,000 pieces of research.

They found positive results in around 50 per cent of patients, regardless of their age, gender, condition (for example, bipolar disorder or postpartum depression) or the type of medication they were taking, if any. Furthermore, partial sleep deprivation – sleeping for three to four hours followed by forced wakefulness for around 20 hours – was just as effective as being deprived of sleep for 36 hours in a single sitting.

"These studies in our analysis show that sleep deprivation is effective for many populations," said Dr Elaine Boland, lead author of the paper published in *The Journal Of Clinical Psychiatry*. "Regardless of how the response was quantified, how the sleep deprivation was delivered, or the type of depression the subject was experiencing, we found a nearly equivalent response rate."

Further study is now needed to determine precisely how sleep deprivation brings around a reduction in the symptoms of depression and to identify those who could potentially benefit the most from the treatment, researchers say.

"FURTHER STUDY IS NOW NEEDED TO DETERMINE PRECISELY HOW SLEEP DEPRIVATION BRINGS AROUND A REDUCTION IN SYMPTOMS"

EXPERT COMMENT

Alice Gregory

Professor of sleep psychology, Goldsmiths, University of London

"The links between sleep and depression are well-established within the field of psychiatry. People who suffer from depression often suffer from insomnia or hypersomnia (excessive sleepiness), for example. Associations are complex, and researchers have investigated whether manipulating sleep might have positive consequences for depression. Cognitive Behavioural Therapy aimed at improving insomnia has led to reduced depression symptoms over time.

The meta-analysis described here focuses on another technique: sleep deprivation. This is a long established technique that seems somewhat counter-intuitive, and lies in stark contrast to the therapy mentioned above. In the meta-analysis, it was found that restricting sleep is a rapid and useful intervention for approximately half of those suffering from depression. I think that this intervention holds great promise. However, it's currently unclear as to how this might be realised. The problem is that when those with depression are permitted to sleep normally again, the benefits tend to disappear.

So while sleep deprivation may not yet be a very useful intervention, the technique could perhaps be developed in ways so as to reduce depression symptoms over longer periods. As the authors note, the next step is to further understand the mechanisms by which sleep deprivation improves mood. Could it help to reset the body clock, perhaps? Could elucidation of the neurotransmitters involved help us to develop treatments in the future? We don't yet know where this knowledge will take us, but meta-analyses of this type are important in telling researchers where we need to go next."

PHOTOS: GETTY, THE FRANCIS CRICK INSTITUTE

GENETICS

HUMAN EMBRYO DNA SUCCESSFULLY EDITED FOR THE FIRST TIME IN THE UK

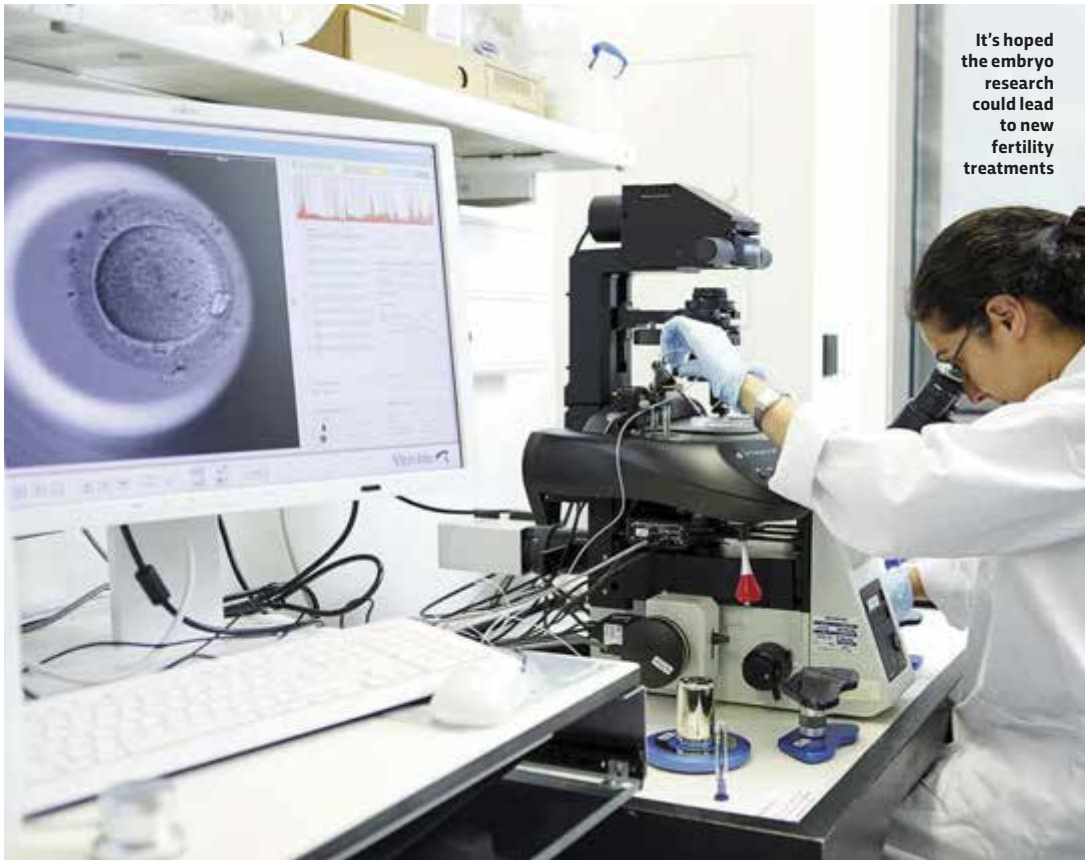
A team at the Francis Crick Institute in London has used DNA editing technology to uncover the role of a gene that plays a key role in the early development of human embryos. The finding could open the door to creating new treatments for fertility problems, developmental disorders, and even adult diseases such as diabetes that may originate during the early stages of life.

The researchers used a DNA editing technique called CRISPR to alter the genetic code of 41 human embryos donated by couples who had successfully undergone IVF treatment. In a regular, healthy pregnancy, the cells in the egg divide for around seven days until they form a ball of around 200 cells called a blastocyst, which then goes on to form an embryo. However, the team found that if they manipulated a specific gene they were able to stop the eggs from producing a protein called OCT4, rendering them incapable of forming into a blastocyst.

"One way to find out what a gene does in the developing embryo is to see what happens when it isn't working. Now we have demonstrated an efficient way of doing this, we hope that other scientists will use it to find out the roles of other genes," said Dr Kathy Niakan. "If we knew the key genes that embryos need to develop successfully, we could improve IVF treatments and understand some causes of pregnancy failure. It will take many years to achieve such an understanding, our study is just the first step."

WHAT IS CRISPR?

CRISPR is a gene-editing tool that acts like a pair of 'molecular scissors', allowing researchers to snip out individual 'letters' of DNA code and rearrange them, altering the gene's function.



It's hoped the embryo research could lead to new fertility treatments

IN NUMBERS

2,370

The temperature, in degrees centigrade, of an asteroid that smashed into what is now Canada 40 million years ago – the hottest temperature of any object ever known to be on the surface of the Earth.

30 MINUTES

The maximum time period we should be inactive for. Moving for at least a few minutes every half hour can help prolong your life, researchers from the University of Columbia say.

30

The percentage of all of the world's known plant species that are currently growing in botanical gardens across the globe.

Artist's impression of Beelzebufo gobbling down a *Masiakasaurus* – a type of small, predatory dinosaur

PALAEONTOLOGY

South American horned frogs (inset) are Beelzebufo's closest living relative, and can be kept as pets – should you choose to

ANCIENT 'PAC-MAN' FROG MAY HAVE DINED ON DINOSAURS

An international team of biologists has found that Beelzebufo, a giant frog that lived about 68 million years ago in what is now Madagascar, would have been capable of eating small dinosaurs.

They reached the conclusion by scaling up the bite force of South American horned frogs from the living genus *Ceratophrys* – Beelzebufo's closing living relative. Horned frogs are often called Pac-Man frogs thanks to their round shape and large, wide mouth.

"Unlike the vast majority of frogs which have weak jaws and typically consume small prey, horned frogs ambush animals as large as themselves – including other frogs, snakes, and rodents. And their powerful jaws play a critical role in grabbing and subduing the prey," said the University of Adelaide's Dr Marc Jones.

The researchers measured the bite forces of horned frogs using a force transducer. This is a device that accurately measures the force applied to two plates covered with leather when an animal bites them. They were able to determine that Beelzebufo may have had a bite force comparable to wolves or female tigers – not too shabby for an amphibian weighing just 5kg. This means it would've been capable of eating small dinosaurs.

"This is the first time bite force has been measured in a frog," said Prof Kristopher Lappin of California State Polytechnic University. "And, speaking from experience, horned frogs have quite an impressive bite, and they tend not to let go. The bite of a large Beelzebufo would have been remarkable, definitely not something I would want to experience first hand."

PHOTOS: GETTY, SHUTTERSTOCK, KRISTOPHER LAPPIN, COLUMBIA UNIVERSITY ILLUSTRATION: DANIEL BRIGHT

HEALTH

SKIN PATCH COULD HELP YOU GET RID OF YOUR 'LOVE HANDLES'

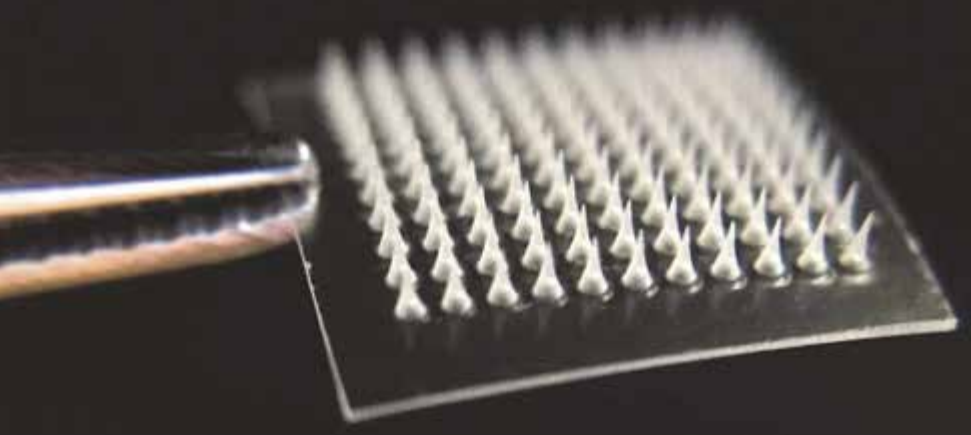
Got a bit of excess baggage around your mid-section you'd like to lose? Help may be on the way. A team at Columbia University has created a medicated skin patch that has successfully 'melted' excess fat in overweight mice.

We all have two kinds of fat – white and brown. White fat stores extra energy in large globular deposits, while brown fat is stored in smaller deposits and can be easily burned to produce heat. Babies have lots of brown fat to help keep them warm but as we age it is gradually lost.

"There are several clinically available drugs that promote browning, but all must be given as pills or injections," said study co-leader Dr Li Qiang. "This exposes the whole body to the drugs, which can lead to side effects such as stomach upset, weight gain and bone fractures. Our skin patch appears to alleviate these complications by delivering most drugs directly to fat tissue."

The patches are covered in microscopic needles that deliver specially designed browning drugs directly to problem areas, where they gradually dissolve. Obese mice treated with the patches showed a 20 per cent reduction in fat and significantly reduced blood glucose levels.

The researchers are currently investigating the effectiveness of different combinations of drugs but hope to start human trials in the near future.



The drugs are enclosed into nanoparticles, each measuring 250nm (0.00025mm) in diameter, before being loaded into the needles

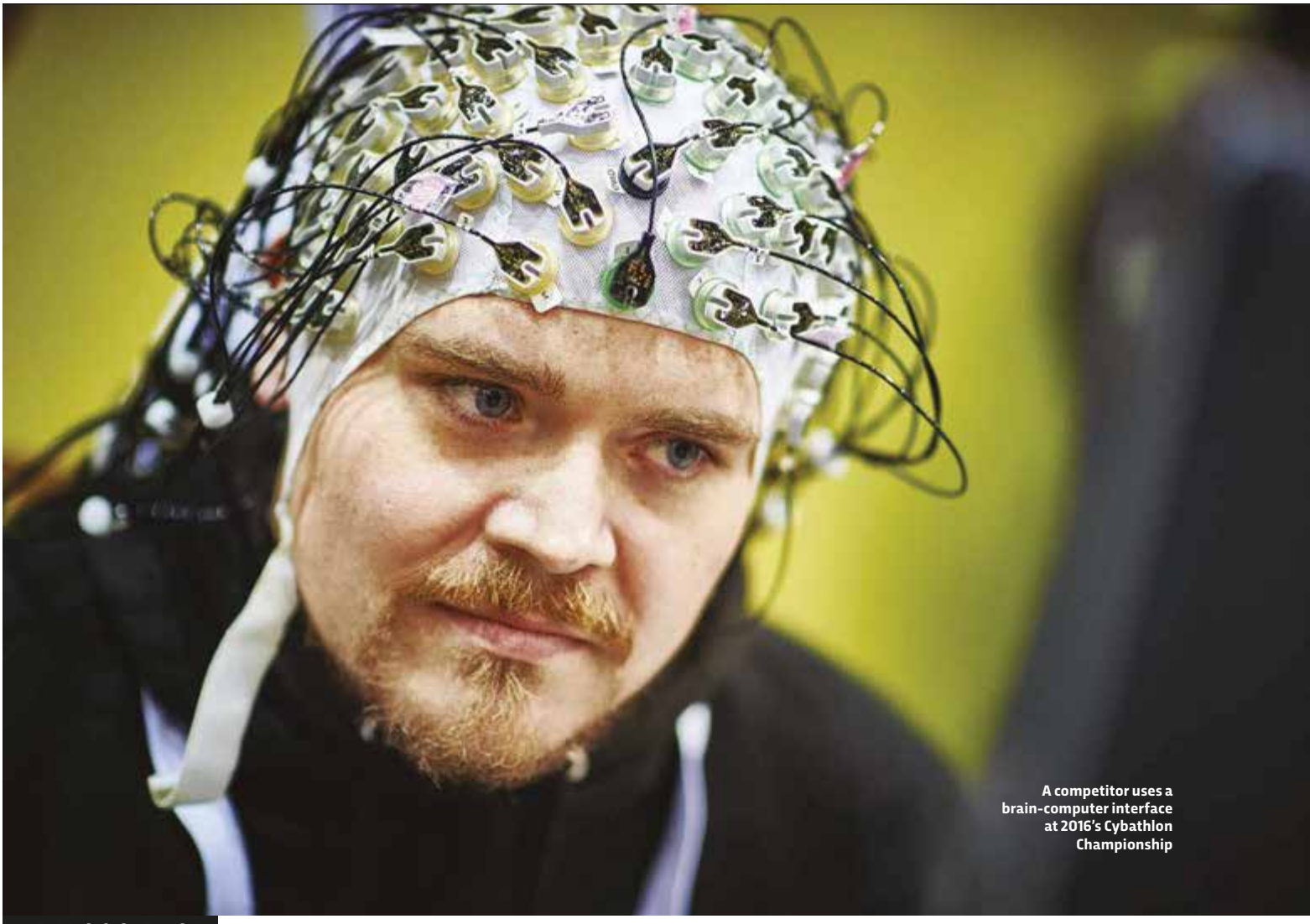
THEY DID WHAT?!

HUMAN MICROBIOME TURNED INTO MUSIC

What did they do?
A team of synthetic biologists and musicians calling themselves Biota Beats created a piece of music using the human microbiome – the symbiotic microbial cells, mostly made up of bacteria, that live on and in the human body.

How did they do that?
The team took swabs of bacteria from their armpits, belly buttons, feet, mouths and private parts and placed them on a petri dish shaped like a vinyl record and let them grow. They then used a mathematical algorithm to translate the images of the bacteria colonies into sounds with a different sound or 'instrument' belonging to each colony.

What does it sound like?
The end result is a spooky ambient electronic symphony that sounds eerily like the sort of thing Aphex Twin might come up with. Have a listen for yourself at biotabeats.org



A competitor uses a brain-computer interface at 2016's Cybathlon Championship

NEUROSCIENCE

BRAIN-COMPUTER INTERFACE ALLOWS MUSIC TO BE COMPOSED BY THOUGHT

Beethoven famously composed several of his masterpieces while he was essentially deaf – but surely even he would be impressed with this piece of research. A team at TU Graz in Vienna has created a brain-computer interface, or BCI, that allows musicians to compose using just the power of their thoughts.

Based on an established BCI that is used to enable severely disabled people to write, the system works by flashing up a series of options – notes, pauses, chords etc – onto a screen placed in front of the user. When the patients focus on their desired options, minute changes occur in their brain waves. These changes are picked up by a special cap fitted with electrodes, and relayed back into the software, which then pieces the user's decisions together to form a musical score of their composition. The project could eventually give physically impaired people an opportunity to express themselves with music, the team says.

"The results of the BCI compositions can really be heard. And what is more important: the test persons enjoyed it. After a short training session, all of them could start composing and seeing their melodies on the score, and then play them. The very positive results of the study with bodily healthy test persons are the first step in a possible expansion of the BCI composition to patients," said study leader Prof Gernot Müller-Putz.

PHOTOS: GETTY, RICHARD WALLBACK/SMITHSONIAN INSTITUTE/UNIVERSITY OF CAMBRIDGE

GENETICS

BUTTERFLY WINGS 'REPAINTED' USING GENE EDITING

Butterfly wings have been given a new look by researchers who used the gene-editing tool CRISPR to alter the colours and patterns of their distinctive markings.

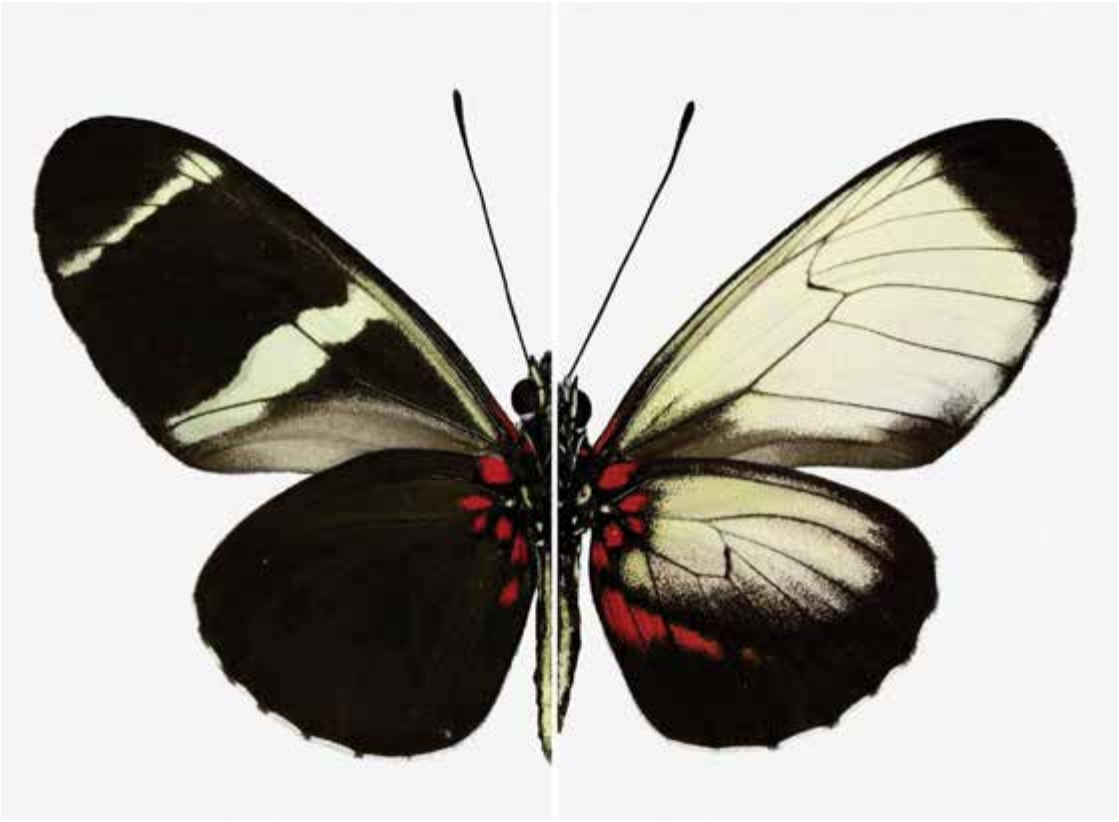
The international team based at the Smithsonian Tropical Research Institute in Panama focused their attention on the WntA gene – a gene known to strongly influence the staggering diversity of shapes and colours found in butterfly wing patterns in nature. They discovered that by 'rewiring' this gene using the DNA-snipping tool CRISPR, they were able to customise the wing markings of seven different butterfly species.

"Imagine a paint-by-numbers image of a butterfly," said researcher Owen McMillan. "The instructions for colouring the wing are written in the genetic code. By deleting some of the instructions, we can infer which part says 'paint the number 2s red' or 'paint the number 1s black'. Of course, it's really a lot more complicated than this, because what is actually changing are networks of genes that have a cascading effect on pattern and colour."

The team hopes that the findings will eventually help them to learn more about how the colourful insects evolved.

"The butterflies and moths, or Lepidoptera, are the third largest group of organisms known on the planet," said Dr Arnaud Martin. "Once we have identified the sets of genes that are regulated by a gene like WntA, we can look at the sequence of different butterflies in the family tree to see when and where these changes took place during the 60 million years of butterfly evolution."

A normal *Heliconius sara* butterfly is shown on the left; the same species that has had its genes edited using CRISPR is shown on the right



THE DOWNLOAD

Bj 581

What's that – BMW's snazzy new hatchback?
Miles off. It's the designation that's been given to the grave of a 10th-Century Viking warrior found in Birka in south-east Sweden.

Cool. So why are we talking about it?
When the grave was first unearthed in the 1870s, the shields, swords, axes and remnants of horses buried alongside the body led researchers to believe it belonged to a male Viking warrior.

But they were wrong?
Yep. A new DNA analysis has found the skeleton only has X chromosomes, and no Y chromosomes. This means it must have belonged to a woman.

Wow! Does that mean this was the grave of a real-life shield-maiden?
Well, there's a bit of disagreement among researchers. Some say that there is still no solid proof the Viking woman was a warrior. Others say that if we automatically assume men buried in such a manner were warriors, then why would we make different assumptions when the body is female?

PETS

"We need better experiments to find out what dogs know"

Dogs don't recognise changes to their own appearance – the 'mirror test' of intelligence. But as dog cognition expert Dr Alexandra Horowitz *explains, there's a reason they fail*

ABOVE: **Dogs may be more intelligent than we realise, despite not passing the mirror test**

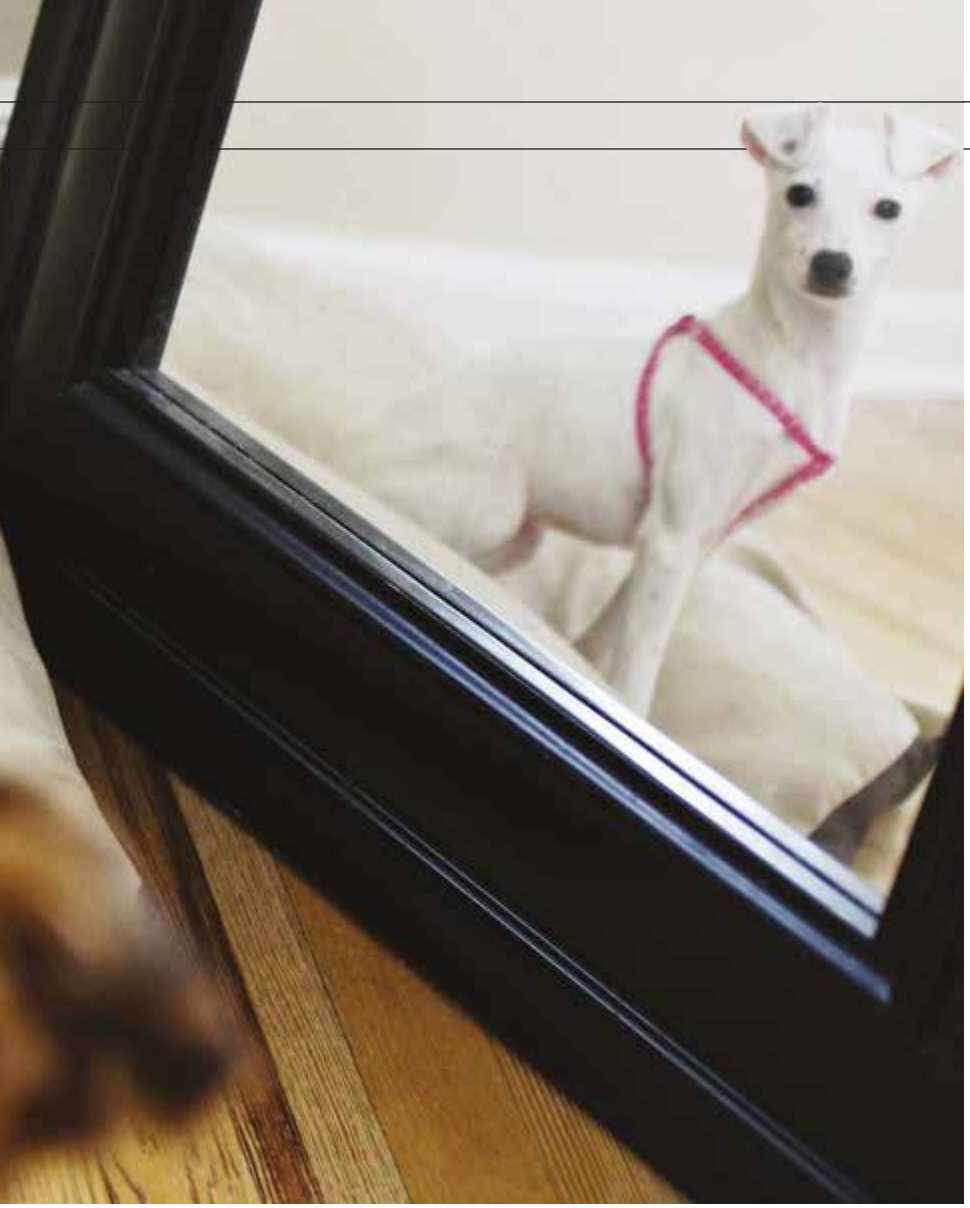
Why is self-recognition a sign of intelligence?
Self-recognition comes out of the comparative cognition field, where people test if non-human animals can problem solve, imitate or learn, just as we would ask of children. Some questions are about meta-cognition – thinking about thinking. One meta-cognitive skill is 'theory of mind' – the realisation that others have minds different from your own, and know things you don't. Humans gain this skill after about the age of three.

What is the mirror test?
This involves looking at yourself in the mirror and recognising that something has changed. The story goes that [psychologist] Gordon Gallup was shaving, and wondered if his captive chimpanzees would look in a mirror and see themselves the way he did. So he put a mirror in their enclosure. They attacked because there was a chimp running at them, but they soon learned and started to examine themselves. He surreptitiously marked chimpanzees on the forehead with an odourless red dye and recorded their behaviour the next time they saw their reflection. His chimps touched the mark on their own head, not the mirror, and tried to smell the dye on their fingers. That was considered passing the mirror self-recognition test.

Which animals pass the test?
Dolphins have passed using marks on their sides and a reflective surface in their aquarium, moving their bodies in unusual ways to see the mark. One African elephant passed the test and magpies have passed. But a number haven't passed, like rhesus macaque monkeys. Dogs don't pass the test. But think about differences in sensory equipment and what's important for animals – whether they live with others, their social organisation, whether they groom themselves. All seem relevant to whether one might pass. With dogs, you have not a visual but an olfactory [scent-driven] creature.

So how did you test dogs?
I looked at a natural dog behaviour: they urinate, leaving information in their pee. They also sniff other dogs' urine markings, so something is communicated, presumably about identity. They're interested in who else is around. So I designed an 'olfactory mirror'. I collected urine from 35 dogs and put small

PHOTOS: GETTY, ALAMY ILLUSTRATIONS: DAN BRIGHT



amounts of the urine into canisters with air holes, then exposed the canisters to the dogs. The dogs spent less time sniffing their own urine and longer sniffing other dogs'. But then I took their odour and added anise (the scent of liquorice) to it. Sure enough, they spent more time sniffing their own odour with this mark.

So are dogs smarter than we think?

We have to take seriously what it's like to be an olfactory creature, and how that revises what their cognition might be. It's possible that dogs have a thorough understanding of themselves. Simply the fact we haven't been able to answer these questions previously shouldn't lead us to assume that dogs don't have the capacity – we just need better experiments to find out what it is that dogs already know.

BELOW: **The mirror self-recognition test was based on an experiment with chimpanzees**

YOGIS

Practising yoga for just 25 minutes a day can boost brain function and the ability to control negative actions, researchers at the University of Waterloo have found. The effect is thought to be due to the release of endorphins and increased blood flow in the brain.

THE CHEERFUL

Being in a good mood when you get a flu jab could boost its protective effect, researchers at the University of Nottingham have found.

GOOD MONTH

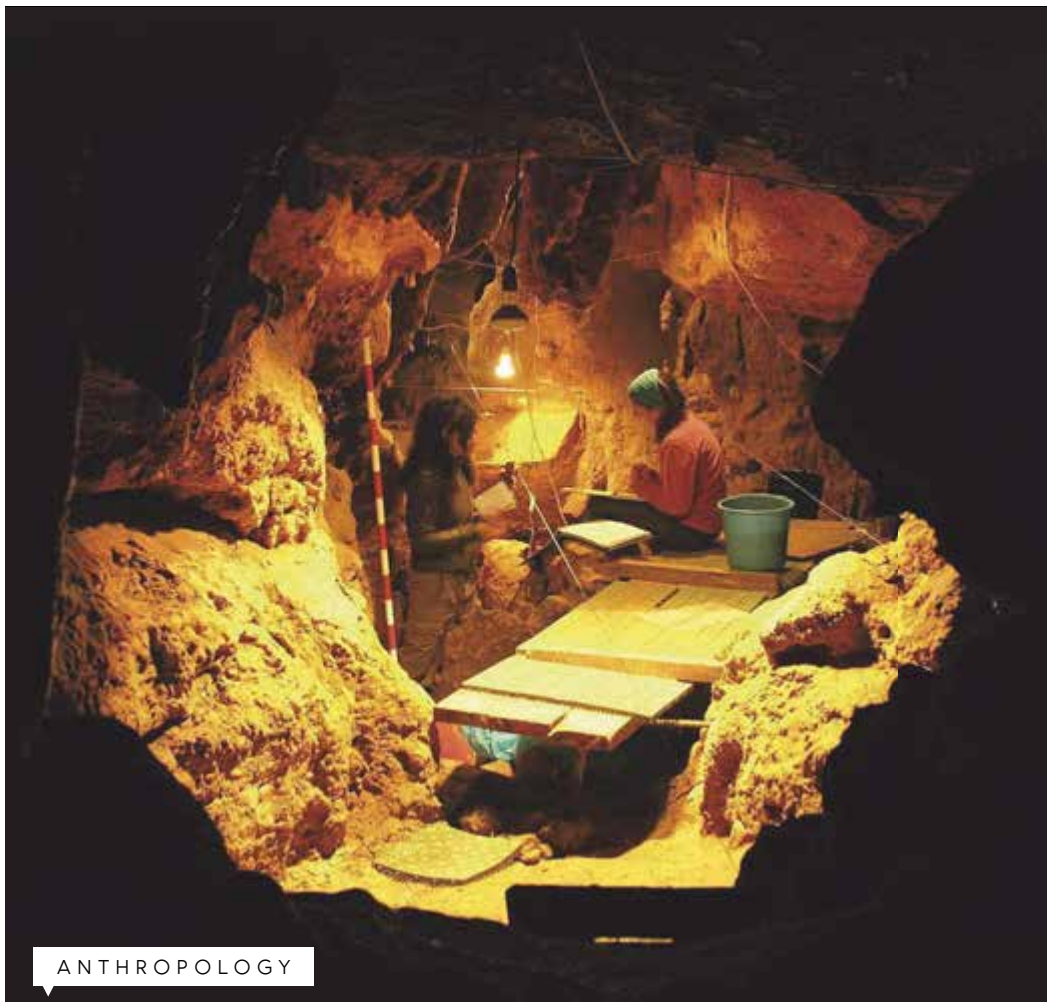
BAD MONTH

PANDAS

The black and white bears recently had their conservation status downgraded due to rising numbers, but all is not well in China's bamboo forests. Satellite images show that their habitat is still smaller than it was 30 years ago.

MEAT LOVERS

Eating lots of processed red meat can raise your chances of getting Type 2 diabetes by more than 20 per cent, a team in Singapore has found. They believe it is due to the high levels of the iron-rich compound heme.



ANTHROPOLOGY

NEANDERTHAL BOY'S SKELETON REVEALS THEY GREW MUCH LIKE MODERN HUMANS

LEFT: **Spain's El Sidrón caves contain Neanderthal fossils and tools, which are of great interest to researchers**

ABOVE: **Skeleton of the Neanderthal boy**

Neanderthals' offspring developed in a very similar way to our own, new research has shown – with the differences in rates of development thought to account for the physical differences between the two species.

A team led by Antonio Rosas at the Spanish National Research Council studied a male Neanderthal child who died aged around eight years old, and whose remains were discovered in the El Sidrón cave in Piloña, Spain in 1994. At the time of his death, he was 111cm tall and weighed 26kg. The Spanish team found that the child had developed to almost exactly the same degree you'd expect to see in an eight-year-old male child today, with two key differences.

First, his brain cavity had only reached 87.5 per cent of its adult size, compared to a modern human child where the brain cavity would already have reached its full size. It's thought this slightly slower rate of brain development enabled Neanderthals to grow larger.

"Developing a large brain involves significant energy expenditure and, consequently, this hinders the growth of other parts of the body," said Rosas. "In *Homo sapiens*, the development of the brain during childhood has a high energetic cost and, as a result, the development of the rest of the body slows down."

Second, the thorax area of the skeleton appears to have more developed more slowly. The Neanderthal specimen's thorax resembled that of a five- or six-year-old human child, with the cartilaginous joints of the middle thoracic vertebrae and the topmost vertebrae yet to fuse.

"The delay of this fusion in the vertebral column may indicate that Neanderthals had a decoupling of certain aspects in the transition from infancy to the juvenile phase. Although the implications are unknown, this feature could be related to the characteristic enlarged shape of the Neanderthal torso, or slower brain growth," said Rosas.

PHOTOS: PALEOANTHROPOLOGY GROUP MNCN-CSIC, SANDRA GOUTTE, ALAMY

ZOOLOGY

ADORABLE BRAZILIAN FROGS CAN'T HEAR THEMSELVES SPEAK

Two species of tiny frogs, known as pumpkin toadlets, which live on the floor of Brazil's Atlantic Forest, are unable to hear their own (and each other's) cries, it has been discovered. This makes them the only two species known to have evolved in this way. The discovery was made by a team of scientists from Brazil, Denmark and the UK, led by Dr Sandra Goutte from Brazil's Universidade Estadual de Campinas.

In order to find a mate, most frog species signal their presence to members of the opposite sex by calls, but making such calls consumes energy and can attract predators. The two species of pumpkin toadlet also make such calls, but laboratory testing at the University of Southern Denmark suggested they are unable to actually hear them, while anatomical studies at Cambridge University confirmed that the part of the ear that would normally detect the high frequencies involved is vestigial in the two species involved. In other words, like the human tailbone, it's still there but no longer does anything.

Jakob Christensen-Dalsgaard from the University of Southern Denmark said: "We have never seen this before: these frogs make sounds that they cannot hear themselves."

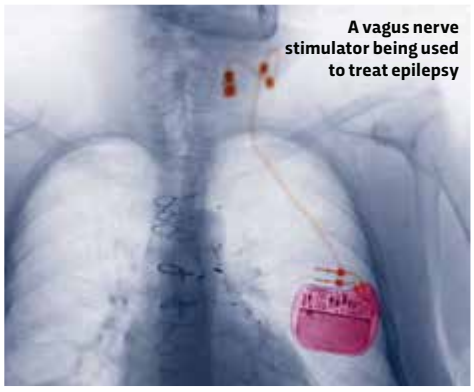
Goutte added: "One would think that if a signal is not perceived by its target audience, it would be lost through evolution."

It's thought that the calls have been retained because the bright orange toadlets have replace auditory with visual signalling, and that the throat-swelling that produces the call is now the way the toadlets attract a mate – with the resulting call now a mere by-product of this visual signal.

The pumpkin toadlets' bright colours warn predators of their toxicity

NEUROSCIENCE

CONSCIOUSNESS RESTORED IN MAN AFTER 15 YEARS IN A VEGETATIVE STATE



A vagus nerve stimulator being used to treat epilepsy

A 35-year-old man who had been in a vegetative state for 15 years following a car accident has shown signs of consciousness after receiving pioneering nerve stimulation therapy. The outcome challenges the belief that disorders of consciousness that persist for longer than 12 months are irreversible.

The procedure, which was carried out by a team of neuroscientists based at the Institut des Sciences Cognitives Marc Jeannerod in Lyon, France, involved implanting a device into his chest to stimulate his vagus nerve – a major nerve that runs down through the body from the brainstem and is involved in walking and many other important motor functions. The same therapy is used to treat seizures.

One month after the implant, the man went from being in a completely vegetative state to being able to turn his head, follow objects with his eyes and listen to his therapist reading a book.

Recordings of brain activity also revealed major changes in areas of the brain involved in movement, sensation, and awareness. After many years in a nonresponsive state, he had entered a state of minimal consciousness.

"Brain plasticity and brain repair are still possible even when hope seems to have vanished," said lead author Dr Angela Sirigu.

The researchers are now planning to extend the study to further investigate the technique.

Cassiopea jellyfish have algae living in their tissues. When the jellyfish lie upside-down on the seabed, the algae is exposed to sunlight so it photosynthesises and provides food for the jellyfish

ZOOLOGY

JELLYFISH SLEEP, DESPITE HAVING NO BRAINS

Science still can't fully explain why we need sleep, but many current theories involve clearing the brain of waste chemicals. A rethink maybe required, however, because research at California Institute of Technology (Caltech) shows that *Cassiopea* jellyfish, which have no brain at all, exhibit similar sleep behaviour to humans and other mammals.

***Cassiopea*, the upside-down jellyfish, are known for sitting on the ocean floor and pulsating. So how can you tell if they're snoozing? Scientists use three criteria to define 'sleep' across the animal kingdom. Is the creature less active? Is it less responsive to external stimuli? And if you deprive it of 'sleep', is it more prone to such a state afterwards?**

The Caltech team monitored the jellyfish 24 hours a day and found that they pulsate about 39 times per minute at night, compared to 58 times per minute by day. In an experiment where a shelf in the water was pulled out from under them, jellyfish in this slower-pulsating state took longer to reorient themshelves on the ocean floor than jellyfish that were 'awake'. Finally, if the jellyfish were 'prodded' with jets of water during the night, they tended to fall into the quiescent state the next day when they would usually be awake.

This suggests that jellyfish, which are an ancient group of animals, do indeed sleep, suggesting sleep may be a behaviour acquired early on in our evolution and never abandoned.

"Jellyfish are the most evolutionarily ancient animals known to sleep," said researcher Ravi Nath. "This finding opens up may more questions. Is sleep the property of neurons? And perhaps a more far-fetched question: do plants sleep?"

THINGS WE LEARNED THIS MONTH

BABIES CAN LEARN THE VALUE OF HARD WORK

A study at MIT showed that babies as young as 15 months old persevered more with tasks they were attempting if they had previously seen an adult struggling hard to achieve something.

FISH HAVE PERSONALITIES

University of Exeter researchers studying Trinidadian guppies found that particular guppies were consistently more cautious, curious or aggressive than others across a range of situations and environments.

MOODS ARE CONTAGIOUS, DEPRESSION ISN'T

A US study has found that teenagers whose friends are in a good or bad mood are more likely to feel the same way – although this doesn't apply if their friends are severely depressed.

GIRAFFES' LONG NECKS MAY BE A COOLING MECHANISM

Giraffes' necks are an evolutionary mystery, but a new study suggests that distributing body mass in this way enables them to present a smaller surface area to bright sunlight, and hence keep cool.

PHOTO: CALTECH

WHY DON'T NATURAL DISASTERS WORRY US MORE?

Humanity ought to wise up on the long-term risks

What would you think if a nuclear-tipped missile zoomed through space and nearly hit a satellite or two? That's pretty close to what actually happened on 12 October this year – except that the 'missile' was under no one's control.

Travelling at over 25,000 km/h, the house-sized chunk of rock known as asteroid 2012 TC4 packed the punch of a few dozen atomic bombs as it flew overhead, at a similar altitude to many communications satellites. Yet after a bit of media coverage, the event soon went the way of all such 'cosmic close shave' stories, and disappeared off the news radar entirely.

Even when one of these objects actually does make it through the atmosphere – as one did over Chelyabinsk, Russia in 2013, injuring over 1,000 people – we all soon forget about it. But are we being too complacent? Many scientists argue that we are, and they claim to have evidence to prove it.

The trouble is, that evidence isn't very compelling. Exhibit A is that the chances of dying in an asteroid impact that trashes the planet are around 1 in 75,000 – that's double the risk of being killed by lightning. But wait, that can't be right, surely? After all, the last time the Earth got totalled was around 65 million years ago, when the dinosaurs were wiped out.

The explanation lies in the fact that this risk depends on more than just how frequent the event is. While massive asteroid impacts are far rarer than lightning strikes, the likely death toll is millions of times higher – leading to that surprisingly high final risk figure.

Multiplying the frequency of the event by its consequences has long been deemed the only scientific way to make decisions about risk – and the theory behind this is pretty solid. But as a way of getting people –and politicians – to take risks of natural disasters seriously, it doesn't really work.

"IT TAKES AROUND 20 YEARS FOR PEOPLE TO PARK THEIR CONCERNS ABOUT A REPEAT OF A PREVIOUS DISASTER"

ILLUSTRATION: DANIEL BRIGHT

That's because the formula is only really helpful for deciding how best to protect the whole of humanity for the rest of eternity. But Joe Public – and especially Sir Joseph Politician – tend to have rather more short-term concerns, such as living long enough to see their kids grow up, or getting re-elected. For them, that is perfectly rational, too. So telling them they're wrong to ignore risks on timescales so vast they'll probably never experience them isn't going to win them over.

Cosmic catastrophes, which typically have timescales of centuries and more, run straight into this timescale problem – which is probably why few people outside academia worry about them. But natural disasters on much shorter timescales can still engender indifference. From California's San Andreas fault to the slopes of Mount Vesuvius, it's clear that millions of people are quite capable of pondering the risks of living on the sites of far more frequent natural catastrophes and deciding they'll probably be okay.

So what kind of timescale *do* people take seriously when assessing such risks? Judging by the response of those living in hurricane zones, it takes less than a generation – around 20 years or so – for people to park their concerns about a repeat of a previous disaster. That's far shorter than the average 'return period' of most forms of natural disaster, such as earthquakes, volcanic eruptions or Category 5 hurricanes.

In one sense, all of this bears witness to the astonishing resilience of the human spirit. But it also highlights a critical limit to human rationality –and a major challenge to those seeking to protect humanity from long-term disaster. Unless they can find some way of circumventing the timescale problem, their pleas for action are likely to be greeted by the classic response of each new generation to the dire warnings of their elders: "Yeah, whatever…".

Robert Matthews is visiting professor of science at Aston University, Birmingham.

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INNOVATIONS

PREPARE Y OMORROW

NOVEMBER 2017 EDITED BY RUSSELL DEEKS

The foldable design makes the Royole Moon easy to slip into your bag, so you can zone out on long journeys

READY FOR LAUNCH

On the following five pages, we offer you a sneak peek at some of the tech and gadgets showcased at IFA 2017, Europe's biggest consumer electronics fair

This may look like a VR headset, but it's actually your own personal 3D cinema. The Royole Moon's 1080p AMOLED visor and integrated noise-cancelling headphones are said to recreate the experience of sitting in front of a curved 20.3m screen, giving an IMAX-like level of immersiveness from the comfort of your sofa. It can also be used to play games from your smartphone, PC or console, while its MoonOS gives access to content from streaming services.

£849.99, royole.com

MIXED REALITY IS HERE

All you need to know about the next stage in the VR revolution

Mixed reality? Is that the same as augmented reality?
Sort of. Mixed reality (MR) refers to any environment where virtual and real worlds collide. So that *could* mean augmented reality (AR) – where virtual objects appear in an on-screen representation of the real world, à la *Pokemon Go* – or it could mean a VR environment that lets you interact with real-world objects. In other words, AR is one form of MR while both are, broadly speaking, forms of virtual reality.

Who are the key players?
Microsoft is leading the MR charge with its Windows Mixed Reality platform, for which headsets are being developed by the likes of Asus, Lenovo, Dell and Acer.

What's the point?
Windows' MR system uses less hardware than a 'full' VR setup – the movement of your hands, for instance, is tracked by cameras on your headset, rather than by external sensors – and no special software is required, because Windows MR will form part of new versions of Windows 10. It's therefore a bit cheaper, though some commenters have suggested that Microsoft just wanted a buzzy new name for what's essentially a late rival to the Oculus Rift and HTC Vive platforms. The first Windows MR headsets should start shipping soon.

STAR WARS: JEDI CHALLENGES

This game consists of a headset, an external motion sensor and a lightsaber. Don the headset, run the app and do battle with Darth Vader or try your hand at dejark, the 'holochess' game from the first film.

£250, disney.com

ASUS HC102

Asus's Windows MR headset is lighter and more comfortable than most, or at least that's what Asus was claiming at IFA! Unlike most headsets the visor flips up if you need a quick reality check.

€449 (£395 approx), asus.com

LENOVO EXPLORER

Lenovo's offering will be available with or without motion controllers. You'll need these if you intend to play a lot of VR games, but not if you just plan to watch 360° videos.

From $350 (£260 approx), lenovo.com

WATCH THIS

Smartwatches are getting more diverse, with models designed for everyone from fitness freaks to fashionistas

GARMIN VIVOACTIVE 3

Garmin is best known for fitness devices these days, but the latest model in its Vivoactive range reaches out to the broader consumer market, too. So yes, it'll monitor your heart rate and save all your run metrics, but it'll also let you make contactless payments via the company's all-new Garmin Pay technology. Meanwhile its battery life – up to seven days between charges – will put most other smartwatches to shame.

£279.99, garmin.com

DIESEL ON FULL GUARD

Diesel's first Android Wear smartwatch features a distinctly 'sci-fi' screen that goes dark in Do Not Disturb mode and, if you're using the Activity Tracker, slowly fogs over when you're not moving, to remind you to get your backside off the sofa. If that doesn't appeal, then bear in mind this is just one of an incredible 300 different smartwatches that Fossil is building for fashion brands like Diesel, Armani and DKNY this year, so one of them's bound to suit…

$325 (£240 approx), diesel.com

SAMSUNG GEAR SPORT

Aimed at the fitness-conscious, Samsung's latest smartwatch has calorie counting/tracking and training apps, the latter guiding you through over 60 workouts and even streaming them to your TV if you're exercising at home. More importantly, it's waterproof to 50m and works with Speedo's Swim Tracking app, making it an obvious choice for water babies. Samsung Pay for contactless payments and offline Spotify support are the icing on the cake.

£TBC, samsung.com

ARROW SMARTWATCH

Okay, we're cheating a bit here, because this wasn't actually on show at IFA. But how could we not tell you about the world's first smartwatch to come complete with its own built-in 1080p 360° camera? The watch also doubles up as a fitness tracker, as well as offering you all the usual notifications for emails, appointments and so on. Prices vary depending on whether you want a silicone, leather or metal strap.

$299-$399 (£220-£295 approx), arrowsmartwatch.com

CAMERA... ACTION!

Cameras came in all shapes and sizes at IFA – here are six of the best

1
RICOH THETA V

Ricoh Theta's new 360° camera is the first to be certified by Google as 'Street View mobile-ready', and is also the first to offer playback of your 360° pictures direct to a television. It's controlled via an iOS/Android app, and can shoot 4K video as well as still images.

$430 (£315 approx), theta360.com

2
LOMO'INSTANT SQUARE

Aimed at Instagram addicts, this all-analogue instant camera uses Fujifilm's widely available Instax film to shoot square, Polaroid-style pics. The modern world gets a look-in too, though, with a 'full auto' mode and remote shutter release.

$199 (£145 approx), lomography.com

3
INSTA360 ONE

This consumer 360° camera from Insta360 retails for under £250, yet can shoot 4K 360° video and 24MP RAW stills, while a particularly neat touch is that its accompanying selfie-stick will automatically be edited out of your footage without you lifting a finger.

$300 (£220 approx), insta360.com

4
SONY RX0

Measuring just 60 x 41 x 30mm, this tiny 4K camera from Sony is designed for use as part of a multi-camera VR setup, or for remote imaging. Waterproof to 10m and crushproof to 200kg, the RX0 will boldly go where no camera has gone before…

$700 (£515 approx), sony.com

5
NIKON D850

This full-frame DSLR boasts a 45.7MP sensor, which would be impressive enough, but it can maintain that resolution at 9fps, while the ISO range (32-102,400) is also impressive. There's an optical viewfinder, a 3.2-inch touchscreen, and it'll shoot 4K video, too.

$3,300 (£2,430 approx), nikon.com

6
FUJIFILM X-E3

Unlike a lot of mirrorless compacts, the X-E3 features a proper optical viewfinder as well as a touchscreen. There's a joystick for focus control, while inside lurks a 24.3MP X-Trans CMOS III sensor. Pictures can be transferred to your laptop or tablet via Bluetooth.

£849, fujifilm.com

The Aurora modular light panels can be arranged however you like, and will react to your music

VOICE WITH EVERYTHING

Amazon's personal assistant continues to find its way into more and more products

The CES show in Las Vegas back in January was flooded with Alexa-enabled hardware. That flood had slowed a little at IFA but not much, and devotees of Amazon's personal assistant/home automation system still had plenty of new goodies to choose from. Want voice control for your robot vacuum, because pressing a button on a remote control is just too damn time-consuming and laborious? You got it.

One item that particularly caught our eye was the Smarter Fridge Cam. As the name suggests, this is a camera that sits inside your fridge and takes a picture of its contents when prompted – which could be kind of useful if you're at the supermarket and can't remember if you need more cheese or not. Quite what you gain from linking this into the Alexa ecosystem we're not sure, though. Of more obvious benefit are the number of higher-end audio products, from the likes of Harman-Kardon, that now have Alexa onboard. If you're going to say "Alexa, play music" then the music that results may as well sound as good as possible, after all.

The usual privacy and security caveats around the Internet of Things apply, of course. But one thing's for sure: in the race to equip everything in our homes with microphones and cameras, Amazon is definitely winning right now.

BOSCH ROXXTER

There were several Alexa-enabled robot vacuums on show at IFA, but this one comes equipped with a camera, so it will double as a home security device, letting you keep an eye on what's going on in the house while you're out and about.

£TBC, bosch.com

HARMAN-KARDON ALLURE

If you want better sound quality in your all-singing, all-dancing, futuristic homestead, then Harman-Kardon has you covered with this stylish, glowing 360° speaker. Intriguingly, though, speakers from JBL (which Harman-Kardon owns) come with Google Assistant instead.

£250, harmankardon.com

NANOLEAF AURORA RHYTHM

Nanoleaf's Alexa-enabled smart lights aren't new but the Aurora Rhythm module, which makes the lights flash in time to music, is – and for our money makes the whole system infinitely more desirable. Although at around £220 for a starter kit consisting of the Aurora Rhythm module and just nine panels, you're talking quite a lot of our money…

€250 (£220 approx), nanoleaf.me

MUSIC

HIT THE DECKS

With vinyl making an unexpected comeback, here are three of the best turntables under £400

Reports of vinyl's death have been greatly exaggerated. In 2014, sales of music on vinyl hit a 20-year high; in 2015, they reached a 25-year high; in December 2016, vinyl sales outstripped sales of digital downloads for the first time since the latter became legally available. It's not just a hipster thing, either – you can now buy records in Tesco and Sainsbury's for the first time in decades. This has led to a boom in sales of vinyl turntables, with high street stores full of sub-£100 'briefcase' models, often complete with built-in speakers.

But those players are often of quite dubious quality: they don't sound great, they're not built to last and the worst offenders can actually damage your precious records. For discerning types – which naturally includes *BBC Focus* readers – that's just not good enough, when for just a little more money you can get something that'll sound much better and last you a lifetime. Here, we put three well-regarded but affordable decks through their paces…

PHOTOS: THE SECRET STUDIO CREATIVE PHOTOGRAPHY

WHAT WE LOOKED AT

SOUND
We tested each turntable with the same five records, from jungle to folk, to see how it could cope across the frequency range.

CONNECTIVITY
Can you hook the turntable up to a PC or Mac to make MP3/WAV recordings? Can it do line-level output or will you need a separate phono stage?

BUILD
Are we looking at a delicate beast that needs gentle handling? Or can you bounce around next to it without the needle jumping?

AESTHETICS
A vinyl turntable is likely to provide a focal point in whatever room you put it in, so does it look as good as it sounds?

REGA PLANAR 2

£375, rega.co.uk

Rega's turntables range from just over £200 to well over £3,500. This £375 model seeks to offer audiophile sound at an everyman price – and it succeeds. It's particularly well-suited to acoustic, folk or jazz: we've never heard Syd Barrett's fragile, airy masterpiece *Terrapin* sound so good, while the fiddle lines in Fairport Convention's *Matty Groves* revealed themselves as never before. It's perhaps not as strong on more bottom-heavy sounds, but it's a tiny minority of golden-eared audiophiles who'll have any grumbles here.

But to bring you such impressive sonic purity at this low price, Rega's had to keep the feature set to a minimum. There's no USB output, no onboard phono stage, and no electronic speed control, so you have to take the platter off and move the belt to switch between 33 and 45rpm, which means this isn't the best choice for anyone who owns, or intends to buy, a lot of vinyl singles. And while the minimal design looks great and is available in black, white or red, the MDF plinth did feel a touch flimsy.

Looks great, sounds fantastic, but not for everyone
8/10

PRO-JECT ESSENTIAL III RECORDMASTER

£349, project-audio.com

The Pro-Ject Essential III has minimal styling and claims to offer true hi-fi sound at a sensible price. It favours 'lighter' music, but less so than the Rega, and for most listeners this won't be an issue.

It's available in a range of different configurations: there are models with Bluetooth or optical digital outputs, for instance. This latest RecordMaster version packs in a wealth of features. There's a USB-B output, which makes digitising your vinyl nice and easy; a felt slipmat, which helps protect your records; and a single button on the bottom left of the plinth, which you press to switch between 33 and 45rpm playback, or press and hold to turn the deck off. On the downside, it's a low-torque beast, so it takes a few seconds to get up to speed. It's also a little susceptible to vibration, and while the externally mounted drive belt will be a definite talking point, fitting the damn thing proved more than a little fiddly (though you'll need to do this once every five years at most).

A great-sounding deck, with a strong feature set
8/10

PHOTOS: THE SECRET STUDIO CREATIVE PHOTOGRAPHY

AUDIO-TECHNICA AT-LP5

£330, eu.audio-technica.com

Audio-Technica's turntable may be the cheapest of the three featured on these pages, but it's also the best all-rounder.

There's electronic speed control and a USB-B output to connect it to a computer, and you also get popular recording package Audacity supplied on disc. Uniquely of the three turntables, the RCA phono output at the rear is switchable between line-level and phone-level, which means if your amp doesn't have a phono channel you can connect it to a line-level input without needing to buy a separate, outboard phono stage. And unlike the Rega and Pro-Ject turntables, which both have straight tonearms, this one features a J-shaped tonearm with a detachable headshell. Tonearm shape (straight or curved?) is one of those long-running 'Mac or PC?'-type arguments that we won't go into here, but the detachable headshell will make changing cartridges a heck of a lot easier. It's also a direct drive machine, which means quicker start-up and no faffing around with belts.

It's not just in the features department that it wins versatility points. *Terrapin* might not have sounded *quite* as spacious as on the Rega, and the bass may not be *quite* as tight as the Pro-Ject, but the sound that comes out is richer and more resonant than the other two contenders and really fills the room. If you listen to a wide range of music genres, you may find that this one performs better across the board, even if it fails to truly excel in any one particular area.

Weighing in at 10.7kg compared to the Rega and Pro-Ject's 5kg and 5.5kg, it's built like a tank and practically impervious to vibration – a definite bonus if you're prone to dancing around the living room!

A versatile beast that packs plenty of punch

9/10

GLOSSARY

CARTRIDGE
A small box that holds the stylus (needle) and connects to the headshell.

HEADSHELL
Sits on the end of the tonearm and holds the cartridge, which in turn holds the stylus.

TONEARM
The straight or curved lever that moves across the record as the stylus follows the groove.

PLATTER
The round plate that spins round and holds the record.

PLINTH
The body of the turntable on which the platter sits.

SLIPMAT
A round piece of felt or similar material that's placed on the platter to protect the record.

PHONO STAGE
A preamp that boosts a weaker, phono-level signal to line-level. Can be built into your amp or the turntable itself, or a separate offboard unit.

THE VERDICT

Let's get one thing clear: there isn't a duffer in sight here, and all three turntables offer impressive value for money. So which one you should buy comes down to personal taste and listening habits.

If sonic fidelity is all that matters, then on sound alone the Rega Planar 2 just nudges it, though if you listen to a lot of dance music, hip-hop, reggae or heavy rock you may find it doesn't pack the bottom-end welly you're after. It's also a nuisance having to remove the platter to change speeds, and you'll need a separate phono stage if your amp doesn't have one. The Pro-Ject Essential III fares a little better at the low end and packs in more features, but loses points for that low torque, which rules out quick changes between records (though you can always hot-swap records with the platter still spinning!). While both those turntables look as good as they sound, the Audio-Technica AT-LP5 is a bit less wow in the looks department and lacks a little high-end definition. It makes up for it with an extensive feature set, its ease of connectivity and sheer sonic 'oomph'.

So if you're likely to be blasting a wide range of music at parties, go for the Audio-Technica, while if you're a jazzbo or folkie who does a lot of solo, late-night listening we'd recommend the Rega. And if you're somewhere between the two, the Pro-Ject deck should suit you nicely!

WHAT YOU'LL NEED

New to all this? Then bear in mind that the three turntables here are hi-fi separates, not all-in-one solutions, so you'll need to connect them to…

AN AMPLIFIER

This strengthens the weak electronic signal from your hi-fi components to a level that's powerful enough to drive a pair of speakers, as well as modifying the tone via bass and treble controls. For use with a turntable, you'd ideally want one with a dedicated Phono channel (see below).

We like: Onkyo A-9010 (£200); Marantz PM-6006 (£279); Pioneer A-30 (£249)

A PHONO STAGE

The electronic signals mentioned above come in two flavours: line- and phono-level. Turntables produce the weaker phono-level signal, which needs to be boosted to line-level by a phono stage (or 'phono preamp') for your amplifier to process it. On amps with a Phono channel this is built-in, while many modern turntables (such as the Audio-Technica AT-LP5) have one onboard. Otherwise, you'll need this extra piece of kit.

We like: Rega Phono Mini A2D (£89); Graham Slee Communicator Gram Amp 2 (£180)

SOME SPEAKERS

Speakers convert the electronic signal from your amp to soundwaves by means of vibrating cones – usually a small 'tweeter' for higher frequencies and a larger 'woofer' for the bass, though high-end speakers sometimes feature a three-way configuration.

We like: Mission LX-2 (£160); Monitor Audio Bronze 2 (£280); Tannoy Eclipse 3 (£300)

Bear in mind that you can often save some cash by buying music equipment secondhand – quality hi-fi gear is built to last, and these days you can pick up some fantastic kit from the 1970s, 1980s and 1990s for very little money!

THE MODERN COCKTAIL

INNOVATION + FLAVOUR

From highly acclaimed mixologist Matt Whiley, AKA The Talented Mr Fox, this unique cocktail book is the perfect inspiration for creating your own delicious and cutting-edge cocktails from scratch.

'People who don't like cocktails like Matt's drinks and people who don't like bartenders like Matt. He is creative, intelligent and driven and it's those qualities that make him the best in the country.'

Michael O'Hare, The Man Behind the Curtain

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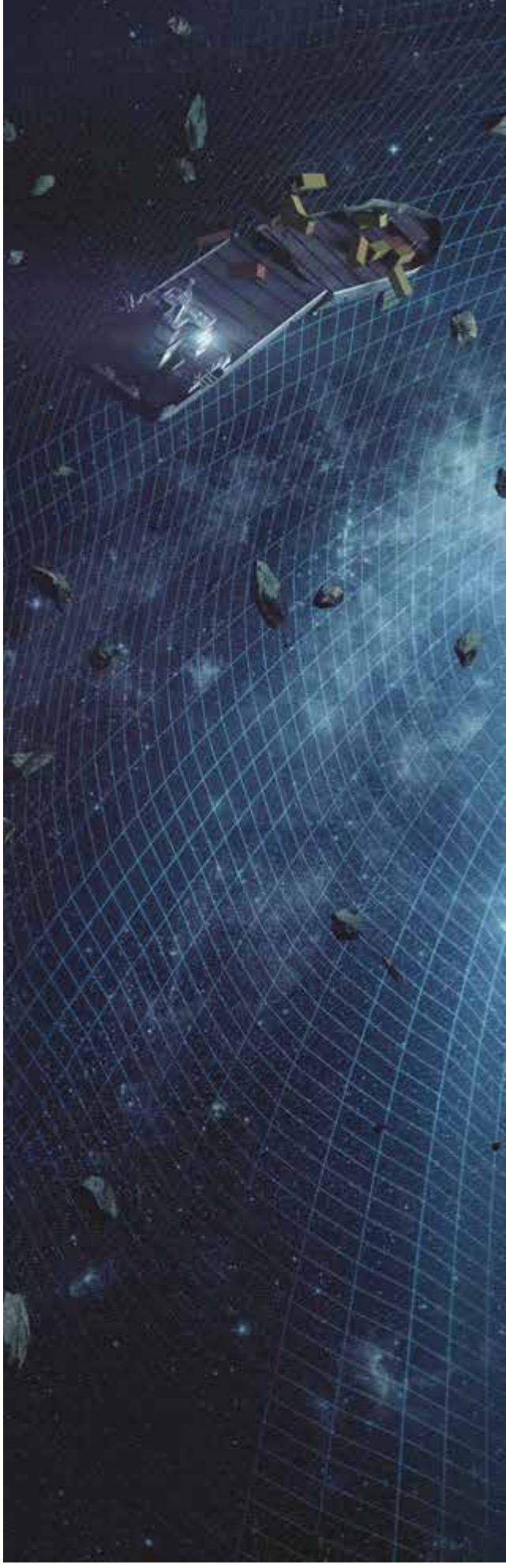
SOMETHING'S WRONG WITH GRAVITY

A new theory could rewrite the laws of physics as we know them, and finally explain what dark matter is

WORDS: ***PROF ROBERT MATTHEWS***



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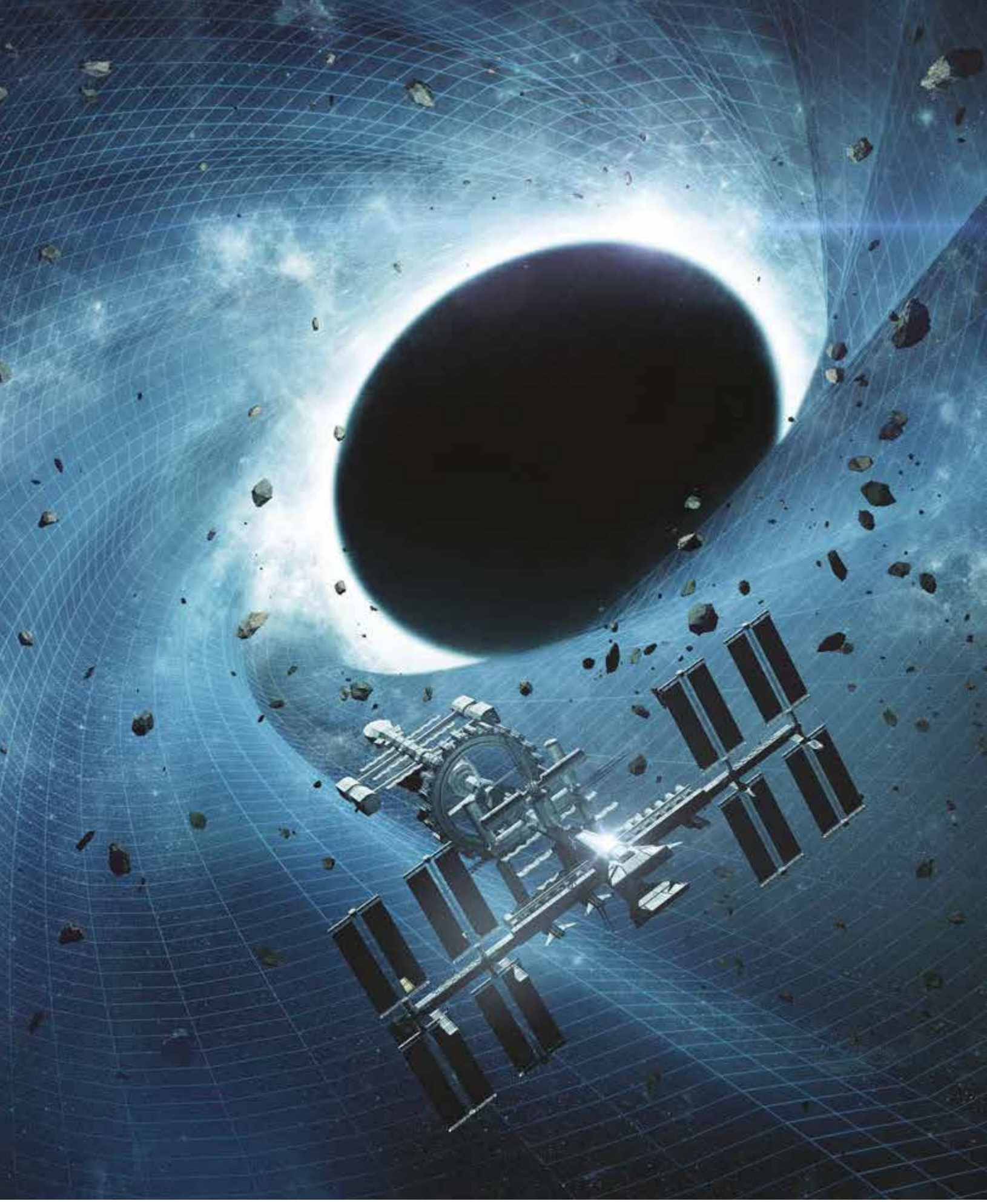
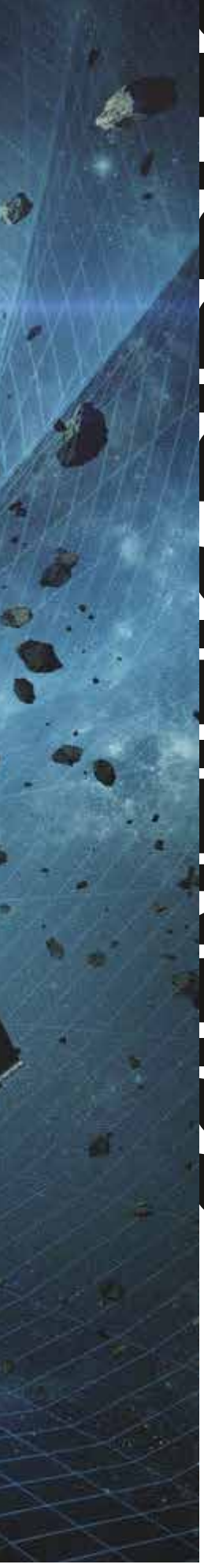




SCIENTIFIC RIDDLES DON'T COME MUCH MORE BAFFLING

Scientific riddles don't come much more baffling than this: entire galaxies seem to be in the grip of something that affects their behaviour, but no one knows what this 'something' is. If it's a form of matter, then it must be the most abundant matter in the cosmos, yet all attempts to get a sample of it have failed. Not even the Large Hadron Collider has seen a glimpse of it. It remains as enigmatic as its name: dark matter.

Now, one theorist has provoked controversy with a devastatingly simple explanation for why dark matter still hasn't been found: it doesn't exist.

But that's not the only reason Prof Erik Verlinde of the University of Amsterdam is attracting so much attention. After all, others have previously suggested dark matter may be some kind of illusion.

What sets Verlinde apart is his explanation for the source of the illusion. He believes it's the result of nothing less than a fundamental misconception about the most familiar force in the Universe: gravity.

It's a claim that brings Verlinde up against the work of some of the greatest minds in science – including Albert Einstein, whose celebrated theory of gravity is one of the cornerstones of modern physics. Known as General Relativity, it has led to a host of triumphs, including the detection in 2015 of gravitational waves – ripples in the fabric of space-time caused by the collision of two black holes.

THE TRUTH ABOUT GRAVITY

Verlinde has spent years piecing together clues from theory and observation to create a whole new vision of the force we call gravity. Now his ideas are being put to the test, with intriguing results. And at the centre of them all is the mystery of dark matter.

Verlinde has been hailed as the intellectual successor to Einstein in the media, yet he sees his goal in more down to earth terms. "I'm just trying to explain where gravity comes from," he says.

That might seem a bizarre statement, coming a century after Einstein showed that gravity is the result of matter warping space and time around it. Yet according to Verlinde, this overlooks the fact that General Relativity remains just a description of the force we call gravity. It leaves unanswered the key question of exactly *how* matter affects space and time.

To carry out his research, Verlinde has had to grapple with some of the deepest problems in science, including the quest for the so-called Theory of

RIGHT: **Erik Verlinde argues that dark matter doesn't exist**

PHOTO: ILVY NJIOKIKTJIEN

Everything – a theory that unites gravity with quantum mechanics that has been considered the holy grail of physics for decades.

Theorists have long known that General Relativity cannot be the last word about gravity. That's because it fails to incorporate the other cornerstone of modern physics, quantum theory. As well as describing the subatomic world with astonishing precision, quantum theory has been able to account for all the fundamental forces of nature apart from one: gravity. Since the 1950s, theorists have tried to marry the two views of nature to produce one overarching theory.

The problem, says Verlinde, is that they are based on such radically different views of reality. For example, General Relativity presumes that it's possible to pin down precisely where particles are and how they're moving, while quantum theory shows that's impossible. "So taking gravity into account gives us a bit of a problem", explains Verlinde.

For years, he worked on superstring theory, which many believe to be the most promising way of overcoming these problems. Yet despite decades of effort and a host of mind-boggling ideas, there is still no hard evidence that it works.

This has led Verlinde down a different path in search for the truth about gravity. The origins of this truth lie in a series of surprising connections between gravity and an apparently unrelated part of science: thermodynamics, the physics of heat.

In the early 1970s, theorists studying black holes – notorious for the intensity of their gravity – discovered they must also be packed with something called entropy. Widely used to understand the behaviour of hot objects, entropy reflects the number of ways of rearranging the constituents of objects without changing their appearance. Calculations showed that black holes contain the highest possible entropy that can be crammed into a given volume of space. But they also ▶

revealed something else. Common sense suggests that as it depends on the constituents of objects, the entropy of a black hole should depend on its volume. Yet theorists found it depends only on the hole's surface area. Stranger still, the calculations suggest the black hole's surface is made up of a vast patchwork of so-called Planck areas. Named after the eponymous German pioneer of quantum theory, Planck areas are far smaller even than a subatomic particle, and appear to be the building blocks of space-time itself.

Pondering these mind-bending connections between the physics of heat and space-time, Verlinde began to wonder if they were hints of a radical new way of thinking about gravity. Heat was once thought to be a fundamental property of matter that exists in and of itself, like electric charge, for example, but it's now known to ultimately be the result of collisions between the millions of atoms and molecules that make up a gas, liquid or solid. The faster the atoms and molecules that make up a material move, the more energy they have and the hotter the material

BELOW: **Visualisation of dust falling into a black hole. The bright flash of light is Hawking radiation – one way in which black holes can lose mass**

PHOTO: SCIENCE PHOTO LIBRARY

JARGON BUSTER

Swot up on your physics with our handy glossary, by popular science writer **Brian Clegg**

ENTROPY

Central to the second law of thermodynamics, entropy is a measure of the disorder in a system. It reflects the number of different ways the components of a system can be rearranged. The letters making up the words on this page have low entropy – there's only one way to arrange them (assuming each individual a, b, c, etc. is unique) to produce the text you're reading. But if you scramble the letters, it will have higher entropy, as there are lots of ways to arrange them jumbled up. The second law of thermodynamics reflects that it's easier to go from an ordered page to scrambled letters than it is to go from a pile of letters to the contents of this magazine. Similarly, it's easier to break an egg than to unbreak it.

FUNDAMENTAL FORCES OF NATURE

Physics recognises four fundamental forces: electromagnetism, which deals with interactions in matter and light; the strong nuclear force, which holds the particles of atomic nuclei together; the weak nuclear force, which is involved in nuclear decay; and gravity. All except gravity fit with quantum theory.

GENERAL RELATIVITY

The General Theory of Relativity, published by Einstein in 1915, explains how mass warps space and time, and how these warps influence the way that matter moves. It provides equations that give us a precise description of gravity, indirectly predicting phenomena like black holes, gravitational waves and the Big Bang.

GRAVITATIONAL LENSING

Einstein's General Relativity predicts that massive objects warp space enough to make passing light curve around them. This means that large cosmic structures like galaxies can act like lenses. Light coming from behind the galaxy is bent around it towards the viewer, bringing distant bodies into focus.

MOND

This stands for Modified Newtonian Dynamics – a theory that expands on Newton's laws of motion. It offers a potential explanation for the unexpected behaviour of spiral galaxies and galactic clusters usually attributed to dark matter. It is based on the idea that the effect of gravity behaves in a subtly different manner on a vast scale. Even so, it still doesn't explain all the observed oddities – but then neither does dark matter.

PLANCK AREAS

German physicist Max Planck mathematically derived the Planck length, a unit of distance around 100 billion billion times smaller than the nucleus of an atom, using constants of nature such as the speed of light. If space is not continuous but made up of quanta – the minimum amount of a physical property that can be interacted with – it has been suggested that its quanta might be a Planck length across (see below for more on quantum theory). Below this distance, measurement would not be possible. A Planck area is a Planck length squared. In black hole theory, when a black hole absorbs a single bit of information, its event horizon – the boundary around it from which not even light can escape – expands by one Planck area.

QUANTUM THEORY

This theory describes the behaviour of light and matter on a very small scale – that of individual particles such as atoms, electrons and photons. The theory takes its name from its central idea that phenomena are not continuous in nature but are instead broken down into tiny indivisible chunks or packets called quanta. In classical mechanics, objects always exist in a specific place at a specific time. But in quantum theory we can only determine the probability of an object being in a certain place at a certain time. This seems counter-intuitive, but the theory is incredibly successful in explaining the interactions of light and matter.

STRING THEORY

String theory was devised to explain inconsistencies in particle physics. It is a leading approach in the attempt to produce the so-called Theory of Everything. In string theory, particles are replaced with vibrating strings, but for the maths to work there need to be nine spatial dimensions rather than the three we observe.

THERMODYNAMICS

Originally developed to provide a theoretical basis for the design and operation of steam engines, thermodynamics – literally the movement of heat – is now a fundamental area of study in physics. It has four laws, of which the most important are the first 'energy is always conserved', and the second 'heat always moves from a hotter to a colder body'. The second law also shows that, on average, in a system that's isolated from its surroundings, entropy stays the same or increases – to decrease it requires energy.

TULLY-FISHER RELATION

The amount of light energy emitted by a spiral galaxy such as the Milky Way is roughly proportional to its speed of rotation. The faster the galaxies spin, the brighter they are. This is known as the Tully-Fisher relation, named after the astronomers Brent Tully and Richard Fisher who discovered it.

"IT IS TIME WE NOT ONLY NOTICE THE ANALOGY, AND TALK ABOUT THE SIMILARITY, BUT FINALLY DO AWAY WITH GRAVITY AS A FUNDAMENTAL FORCE"

appears. Thus heat is actually an 'emergent' property. So could the supposedly fundamental force of gravity also be emergent, its real origins being linked to entropy and those incredibly tiny Planck areas of space-time?

NEWTON AND EINSTEIN

In 2010, Verlinde created a stir among theorists when he published a paper showing how his theory could be used to accurately derive both Newton's and Einstein's laws of gravitation. "The similarities with other known emergent phenomena such as thermodynamics have been mostly regarded as just suggestive analogies," declared Verlinde. "It is time we not only notice the analogy, and talk about the similarity, but finally do away with gravity as a fundamental force."

While intriguing, many theorists remained unconvinced the finding was anything more than a quirk of physics. Verlinde needed to come up with something that didn't merely reproduce existing theories, but predicted something new – and testable. He now believes he's found it with the enigma of dark matter.

While hints of its existence emerged over 80 years ago in studies of clusters of galaxies, it was a discovery of a curious effect inside galaxies that first convinced astronomers to take dark matter seriously.

According to Newton's law of gravity, stars further from the centre of a galaxy should orbit more slowly than those closer in. But during the 1970s, studies of stars within spiral galaxies showed that beyond a certain distance from the centre, this effect simply vanished. The most obvious explanation was that the stars were being affected by the gravity of an invisible cloud of matter surrounding the galaxies. It soon became clear that whatever this stuff was, it couldn't be made from the standard building blocks of matter. That sparked a global effort to detect a viable alternative, which continues to this day – with no success.

This has led to growing suspicions that the most obvious explanation is ➲

simply wrong. In 1983, physicist Prof Mordehai Milgrom of the Weizmann Institute in Israel, pointed out a curious fact about the galactic evidence for dark matter: it can also be explained if Newton's law fails to accurately explain the motions of stars in the outer reaches of galaxies feeling an acceleration due to gravity at a rate less than a certain critical value: around 100-billionth that generated by the Earth.

TESTING, TESTING

While intriguing, what Milgrom called Modified Newtonian Dynamics (MOND) simply replaced one mystery with another: where did this 'critical acceleration' come from? That's what Verlinde decided to find out using his ideas of emergent gravity. "I quickly found a back-of-the-envelope calculation that might explain it, but I had to work for a number of years to make this more precise," he says. And now believes he has succeeded.

The key lies in the effect of the entire Universe on the vital ingredient needed for the existence of gravity: entropy. According to both Newton and Einstein's theories, the entropy of objects like black holes increases with their area. But Verlinde has shown things change on the scale of the whole Universe, because of dark energy. First identified in the 1990s, dark energy is a kind of anti-gravitational force that is propelling the expansion of the Universe. Its origins remain mysterious, but calculations by Verlinde show that dark energy leads to entropy increasing with volume, not just area. That changes the behaviour of gravity at cosmic scales – and, says Verlinde, the result is an acceleration effect creating the illusion that dark matter exists.

"In an expanding Universe, the gravitational laws have to be adjusted at the acceleration scale indicated by MOND," he says. Unlike MOND, however, he has been able to calculate the effect using basic physics.

Verlinde's theory does more than explain why dark matter has never been found. Astronomers have long been puzzled by a 'law' linking the brightness of spiral galaxies to their spin rate. Known as the Tully-Fisher relation, it makes no sense using conventional theories of gravity, but Verlinde has shown that it's a natural consequence of the link between gravity and entropy.

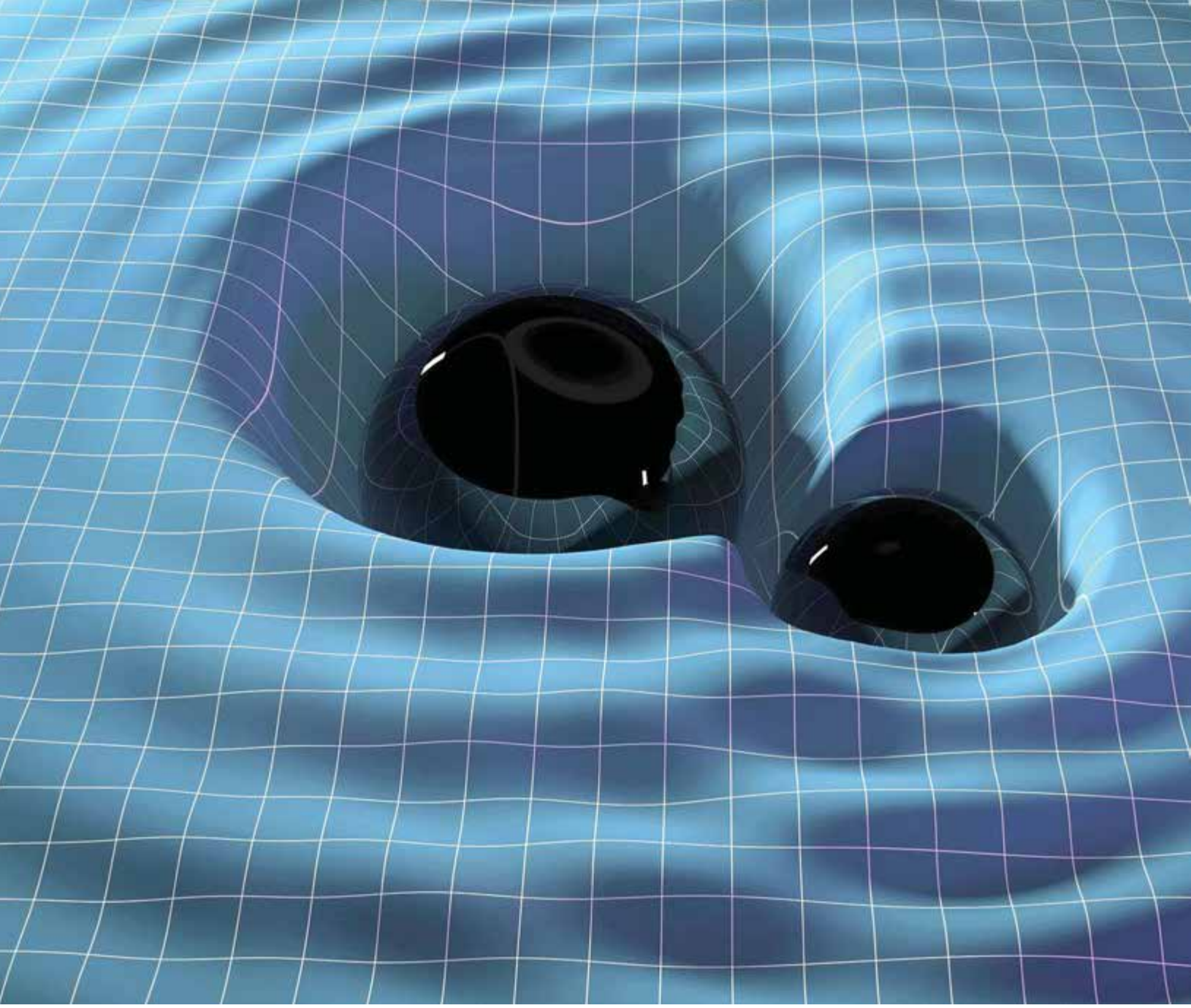
Further evidence backing Verlinde's theory comes from recent studies of the light from distant galaxies. According to Einstein, the gravity field of galaxies can bend the path of light rays. This is known as the 'gravitational lens' effect. An international team of astronomers has found that this effect is consistent with the predictions of Verlinde's theory, without the need for dark matter.

Now the search is on for evidence that Verlinde's theory does not just explain MOND, but outperforms it. And here some problems have emerged. Astronomer Dr Frederico Lelli and his colleagues at the European Southern Observatory have been studying the orbits of stars in galaxies, and they're not behaving as expected. "Verlinde's theory predicts a stronger gravitational pull than MOND in the inner regions," explains Lelli. But this effect doesn't seem to

"WE'RE IN A PERIOD WHEN IT IS NECESSARY TO EXPLORE MANY NEW IDEAS, AND IT TAKES A LONG TIME FOR SUCH THINGS TO SETTLE OUT"

BELOW: **According to the Tully-Fisher relation, the faster a spiral galaxy spins, the brighter it will be**

PHOTOS: GETTY X2



ABOVE: **Visualisation of two black holes orbiting each other, warping space-time and emitting gravitational waves**

exist: "This seems to be a serious issue," he says.

The biggest problem facing Verlinde, however, is explaining a cosmic 'coincidence'. Why does the amount of dark matter needed to explain galaxy rotation curves match the amount needed to explain observations of the early Universe? "The observational evidence for dark matter from a variety of methods is all amazingly consistent," says astrophysicist Prof Neta Bahcall of Princeton University.

The simplest explanation is that dark matter really does exist, but just hasn't been found yet. But Verlinde points out that his work on the nature of gravity is far from complete. "To explain these effects one has to develop the theory to the point where one can describe the cosmological evolution of the Universe," he says. "I am currently working on these ideas, but it will take some time."

Given the huge pay-off if he's right, many scientists are willing to cut Verlinde some slack. "We're in a period when it is necessary to explore many new ideas," says astronomer Prof Stacy McGaugh of Case Western Reserve University, Ohio. "And it takes a long time for such things to settle out."

Prof Robert Matthews is visiting professor in science at Aston University, Birmingham.

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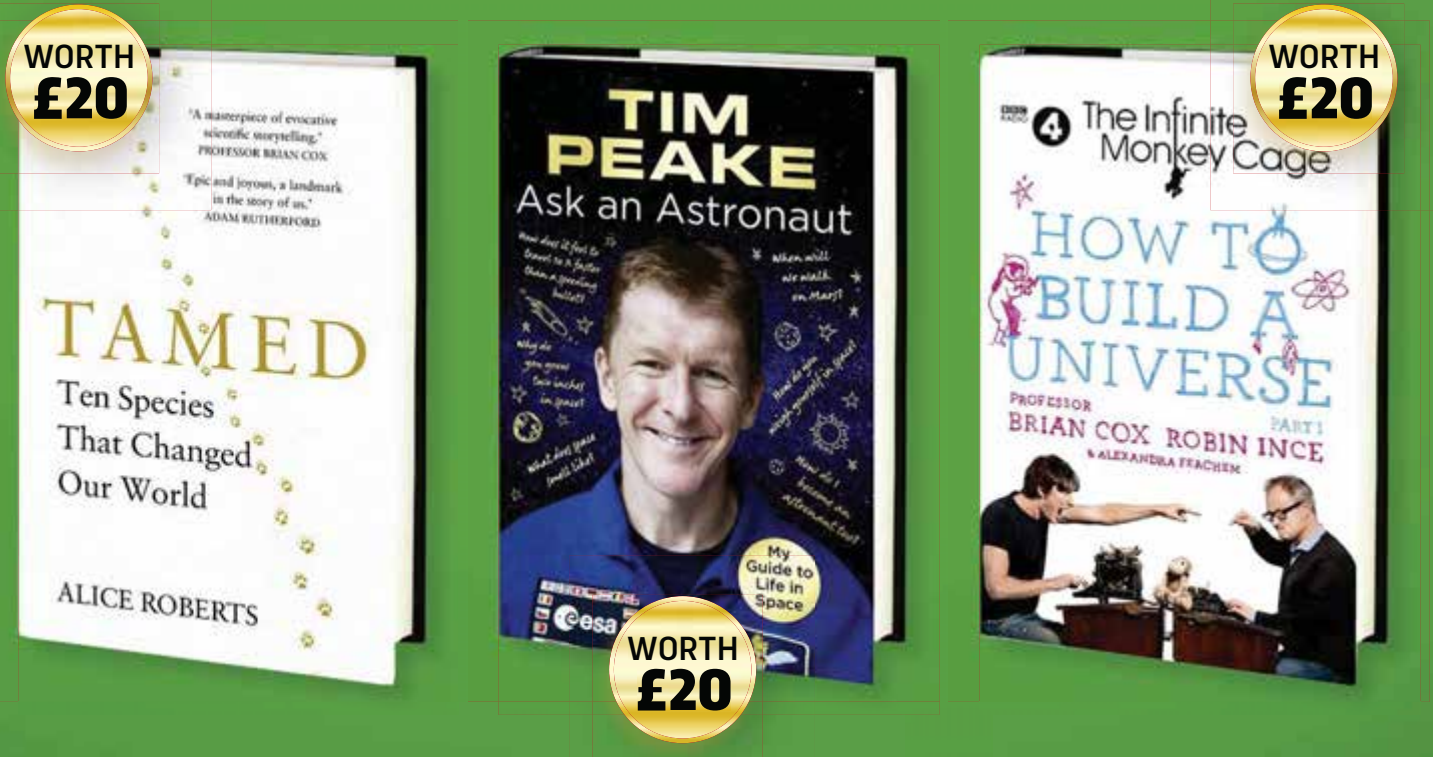

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HOW TO SOLVE THE PLASTIC PROBLEM

By 2050 there could be more plastic in the sea than fish. With *Blue Planet II* airing this month, we take a look at some genius inventions that could help clean up our oceans

WORDS: JOSH GABBATISS

There are over five trillion pieces of plastic in the world's oceans. The floating island of rubbish that's supposedly found at the centre of the Pacific Ocean, dubbed the 'Great Pacific Garbage Patch', has captured the public's imagination, but even this doesn't do justice to the problem. In reality, if you stood on a boat at that site you would see no enormous plastic island, but rather endless tiny fragments floating on the surface of the ocean. According to one estimate, this plastic soup covers an area twice the size of the continental United States.

As plastic moves through our seas it breaks down into smaller pieces – the kind of pieces that can easily be swallowed by marine life. And the problems continue beneath the surface. Scientists are increasingly finding deposits of plastic at the bottom of the oceans, even as far down as the 10km-deep Mariana Trench in the Pacific.

The facts are horrifying, but many of the impacts that plastic will have on ocean ecosystems, marine creatures and, by association, us, remain to be seen. Scientists and entrepreneurs are currently working on ways to halt the flow of plastic into our oceans, and get rid of the stuff that's already there, before the problem gets even worse.

CAPTURE IT

Perhaps the most natural response to the plastic problem is to try to clean up what's already there. "Of course clean-up is really important," says Prof Richard Thompson, head of the International Marine Litter Research Unit at Plymouth University, "and it's our first reaction as humans when we've made a mess." Such reactions vary wildly in scale, from local 'beach cleans' to large-scale, high-tech projects launched by the likes of The Ocean Cleanup.

The Ocean Cleanup was initially conceived by the then ▶

The barriers that The Ocean Cleanup will deploy measure 1-2km in length and aim to capture larger plastics before they degrade

18-year-old Dutch entrepreneur Boyan Slat. His highly ambitious project aims to use huge barriers to passively trap plastic as it moves around ocean gyres – the large circulating currents that keep the floating plastic in place. By anchoring the barriers in deep, slow-moving water, the idea is that the system will move slower than the plastic surrounding it, allowing the debris to accumulate against the barrier. The team behind the project estimates that deployment of their systems could clean up approximately 50 per cent of the Great Pacific Garbage Patch within five years. It's an exciting proposal, and one that has captured people's imaginations, most notably venture capitalists like Peter Thiel who have followed through on this enthusiasm with sizeable cash injections. In total, The Ocean Cleanup has received $31.5m in donations since its inception back in 2013. The team is aiming to roll out a pilot study in the North Pacific around March 2018, and their first fully operational system will be launched later in the year.

While it may be appealing to the great and the good of Silicon Valley, The Ocean Cleanup has attracted its fair share of criticism from the scientific community. Concerns have been raised over everything from the viability of the proposed barriers to their effects on local ecosystems. Perhaps the biggest issue raised, however, is that glamorous initiatives like Slat's draw attention away from the key problem, which is the sheer quantity of litter entering the seas. "It's a little bit like you're filling the bath, you leave the taps on and go downstairs to make a cup of tea," says Thompson. "Then you come back upstairs to find the bath is overflowing – do you start by mopping up the floor, or do you start by turning off the tap?"

What worries Thompson and others is that projects like The Ocean Cleanup overcomplicate an issue that requires basic work to be done first. "If I were a rich philanthropist with money to invest in solving the problem, I would be putting 99 per cent of my money into stopping the flow, and 1 per cent into clean-up," he says.

Dr Matthew Savoca, who studies the effects of plastic pollution on marine life at the NOAA Southwest Fisheries Science Center, has a more positive take. "Assuming it doesn't scoop up more ocean life than plastic, why not give it a shot?" he says. "However, I think [The Ocean Cleanup] would be most effective at or near the mouths of large commercial harbours and at the mouths of rivers, since we know that's how most plastic gets out to sea in the first place." While this is not the stated aim of that project, a far smaller device – the Seabin – has been designed by two Australians to clean up rubbish in just such areas. Using solar-powered pumps, Seabins sit at the surface of the water and suck in the debris that accumulates around harbours and other seaside structures.

Another suggestion for plastic collection involves underwater drones. These autonomous vehicles could

> "If I were a rich philanthropist, I would be putting 99 per cent of my money into stopping the flow [of rubbish], and 1 per cent into clean-up"

WHAT'S THE ALTERNATIVE?

Can we reduce our reliance on plastic? Here are five innovative materials that are in development

1 CARBON DIOXIDE AND SUGAR

As plastics tend to be made using fossil fuels, the search for alternatives is part of the journey towards a more sustainable future. Currently, 4 per cent of global oil production goes into plastic, but scientists are exploring ways to bring this down to zero. A sugar- and carbon dioxide-based substitute for the plastic polycarbonate (used for spectacles lenses, DVDs and greenhouses) has been developed by a team at the University of Bath. Not only does their method bypass fossil fuels, but the resulting material is transparent, strong and biodegradable.

2 AGAR

Easily extracted by boiling red algae, agar is used to make confectionery in Japan. In a project called Agar Plasticity, the Tokyo-based design collective AMAM suggested that this gelatinous substance could be a viable plastic alternative. By heating agar, pouring it into moulds and then freezing it, the team was able to make a selection of plastic-like products and packaging (the bottle pictured has been wrapped with the agar 'plastic'). The designers are now looking to partner with industry so that they can access the scientific and technical knowhow to take their idea to the next level.

3 FUNGI

The bulk of a mushroom's body consists of a mass of underground filaments called the mycelium. By employing mycelia grown on agricultural waste, New York company Ecovative Design is creating a new plastic alternative. A mixture of fungi and their food source can be placed into a mould, such as food packaging or a piece of furniture. Then, once the mould has become filled with a dense mass of mycelia filaments, it is heat-treated to kill off the fungi, leaving a product that is durable but also totally biodegradable.

4 EDIBLE PACKAGING

Food and drink packaging is going to require a huge overhaul if we are to solve the plastic problem. One viable option could be packaging replacements that are just as edible as the products they contain. An example is Skipping Rocks Lab's 'Ooho!', an edible sphere of water made from seaweed extract that you can pop into your mouth (pictured). The US Department of Agriculture, meanwhile, has developed a replacement for the thin plastic films used in food packaging, made from the milk protein casein. Not only are these films biodegradable, sustainable and edible, they are also far better at preventing food spoilage than plastic. Talk about win-win.

5 CHICKEN FEATHERS

Enormous quantities of feathers are produced as a by-product of the poultry industry, and they are generally treated as waste. However, despite their soft and fluffy structure, feathers are composed almost entirely of keratin, a tough protein also found in animal hooves and horns. This means that in theory they could be used as strong, structurally sound, natural replacements for regular plastics. Researchers at the University of Nebraska-Lincoln have attempted to harness this potential, by pounding feathers into a fine powder, then mixing with chemicals to make the keratin molecules bind together.

PHOTOS: ERWIN ZWART/THE OCEAN CLEANUP, KOSUKE ARAKI, ALAMY

WHERE OUR PLASTICS GO

Around 300 million tonnes of plastics are produced annually

As of 2015, 8.3 billion tonnes of plastics have been produced by humans since the early 1950s

Of the 8.3 billion tonnes, 6.3 billion tonnes has become waste

By 2050, the total amount of plastic produced by humankind is projected to have risen to 34 billion tonnes

Over 480 billion plastic bottles were sold in 2016 – that's more than 60 bottles for each person on the planet

New bottles are made from only 6.6 per cent recycled plastic

Up to one trillion plastic bags are discarded every year too

Only around 9 per cent of plastic gets recycled

12 per cent gets incinerated

The rest accumulates in landfills or the natural environment.

As much as 13 million tonnes of plastic enters the ocean globally each year – equivalent to the mass of around 85,000 blue whales

The amount of plastic entering the oceans is expected to more than double within 10 years

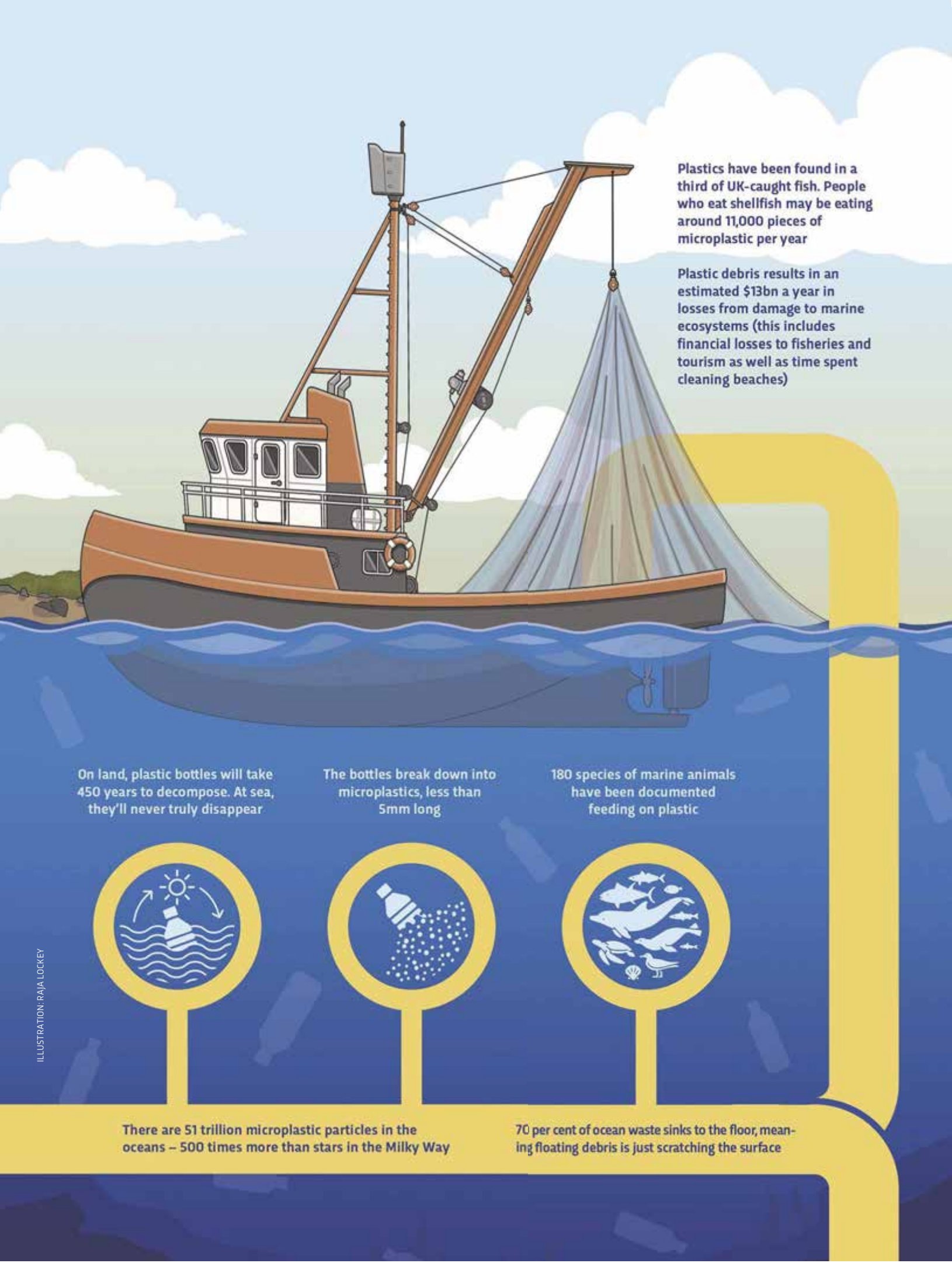

ILLUSTRATION: RAJA LOCKEY

ABOVE LEFT AND RIGHT: **A total of 5,000 tonnes of litter was cleared from a 2.5km-long stretch of Mumbai's Versova beach over the course of 85 weeks. Before the volunteers set to work, waste was piled over 1.5m high**

BELOW: **Seabins are designed to collect rubbish from harbours and ports, and can suck in 1.5kg of floating waste per day**

whizz around plastic-saturated areas of the ocean, swallowing rubbish with their circular 'jaws' while keeping fish away using a sonic transmitter.

These are ingenious solutions, and maybe a bona fide success story will help to ease the tension between those developing the projects, and the people who want to prevent the plastic getting there in the first place. After all, as Savoca points out: why not do both?

GOBBLE IT UP WITH MICROBES

Bacteria are potentially the most versatile creatures in existence, capable of making a home in pretty much any environment on Earth. It is perhaps unsurprising, then, that in recent years scientists have found evidence that some have evolved the capacity to break down plastics. Last year, for example, a Japanese team identified a bacterium capable of biodegrading PET – a plastic found in everything from polyester clothing to water bottles – prompting speculation that bacteria could be employed to stem the tide of plastic pollution by munching through it.

Dr Linda Amaral-Zettler, a microbial ecologist working on the 'plastisphere' – the community of creatures living on ocean plastics – says it's wrong to think of plastic as a sterile environment. "When you do the experiments, you find there are some microbes that are incredibly well suited to colonising plastics," she explains. Her work has shown distinct genetic differences between bacteria inhabiting plastic and those in the surrounding water, so the concept of bacteria adapting to life in the Plastic Age is not that far-fetched. "But it's one thing to colonise, it's another to actually break down and digest plastic," she adds.

While plastics do degrade naturally through UV radiation and physical processes, and bacteria may be playing some role in this, it doesn't mean all the plastic is simply vanishing into their tiny bodies, never to be seen again. In fact, some microbes might even be breaking down the plastic into ever smaller particles, which are not only harder to detect and clean up, but could be damaging marine ecosystems. Plastic-munching microbes are an intriguing area of research, and certainly worth exploring further. But with the plastic piling up fast, we might not be able to rely on bacteria to do our dirty work for us.

TURN IT INTO SOMETHING ELSE

Ultimately, plastics are not our enemy. They are durable,

PHOTOS: ALAMY, AFROZ SHAH

lightweight, inexpensive, and incredibly useful. The major issue is that around 40 per cent of the plastic we produce is going into single-use items, such as cotton buds, drinking straws, carrier bags and plastic forks, which have a long life following disposal.

Fortunately, we're beginning to see more projects that repurpose discarded plastics. Not only can plastics be recycled to make the usual suspects, such as packaging, but they can be transformed into more specialist products such as clothes. Some companies, for example, melt down plastic bottles and turn them into fibres that can be woven into fabrics, a process that uses 50 per cent less energy than producing polyester, the plastic most widely used in clothing, from scratch.

Plastics can also be used as fuel, with new technologies allowing us to efficiently convert them into diesel and gasoline. By heating plastic in a controlled way, coupled with a catalyst, it is possible to produce fuel that doesn't even need refining and is ready to use. All of this means less plastic leaking out of the system and ending up in the oceans. Eventually, we could see a fully circular 'plastic economy', though this would require major changes at an industry level in order to make plastic easier to recycle and reuse.

Josh Gabbatiss is a science writer based in London. He tweets from @Josh_Gabbatiss

HOW YOU CAN HELP

1 AVOID SINGLE-USE PLASTICS

The culprits here should be familiar to everyone: carrier bags, bottles and drinking straws. Purchase a 'bag for life', carry a reusable bottle, and sip drinks straight from the glass.

2 GIVE UP CHEWING GUM

Chewing gum is made from synthetic rubber – a plastic – and shockingly around 100,000 tonnes of the stuff is discarded every year. Is minty-fresh breath really worth that?

3 GO ON A BEACH CLEAN

Organisations like the Marine Conservation Society conduct cleans up and down the country, removing rubbish from the beaches and raising awareness of the ocean environment.

4 RECYCLE!

We've all heard this one by now, but currently only a third of recyclable plastic used by UK consumers is recycled. So swot up on your local rules and get into the recycling habit!

5 GO MICROBEAD-FREE

A UK ban is coming into force in 2018 for many products containing microbeads. Be wary: it won't cover 'leave-on' products such as sunscreen and make-up, so read ingredients lists.

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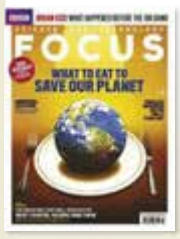

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PHOTO: GETTY

WILL WE EVER BE ABLE TO FORECAST THE WEATHER?

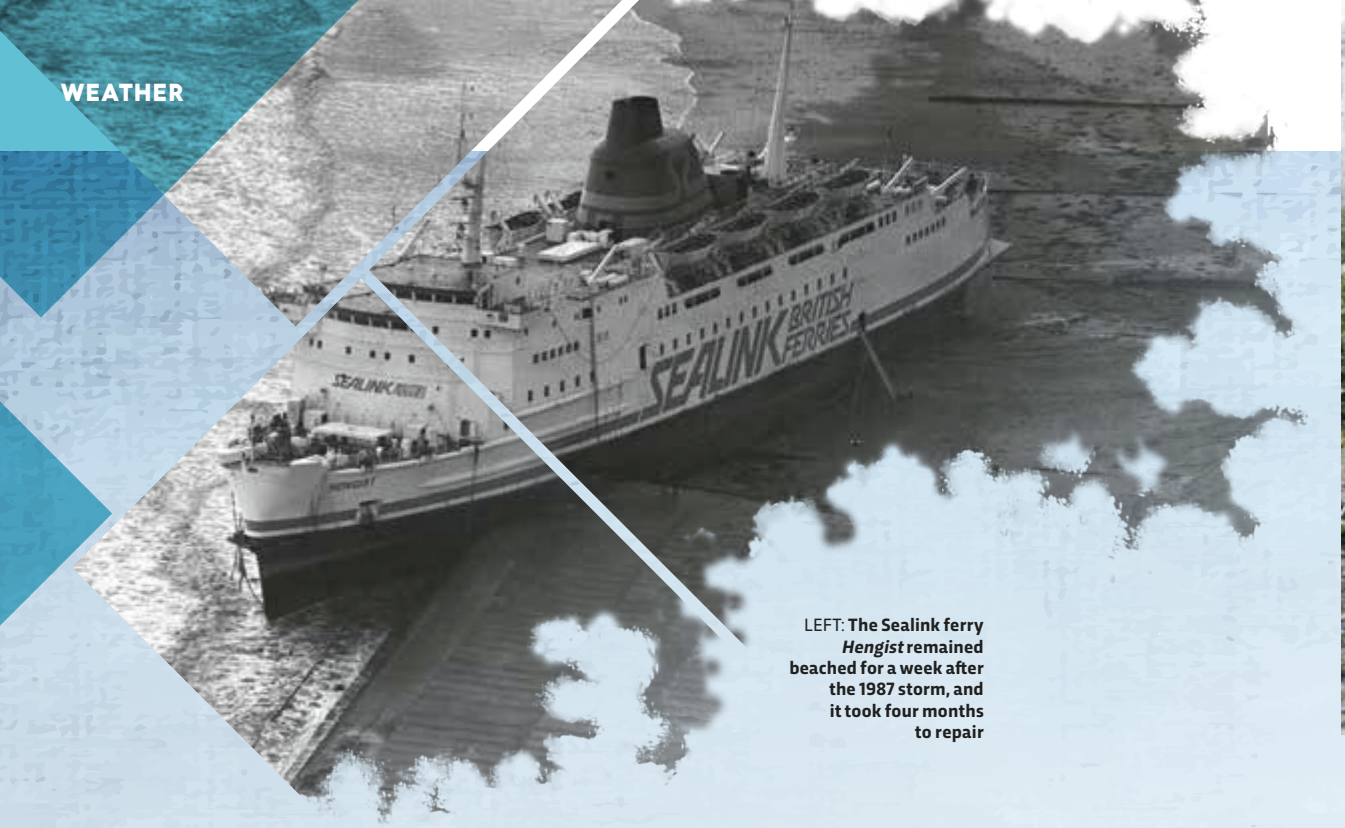
In October 1987, the Great Storm wreaked havoc across the south of the UK, taking everyone by surprise. Now, 30 years on, why do we still have trouble predicting the weather?

WORDS: DUNCAN GEERE

On the morning of 16 October 1987, southern England woke to a scene of devastation. Eighteen people were dead, and thousands of homes were without power. Fifteen million trees had fallen across the country, irreparably changing the landscape and blocking roads and railways. In Folkestone, a 110-metre Sealink ferry was discovered marooned on the beach. A pier on the Isle of Wight was almost totally demolished.

The culprit was the Great Storm of 1987, as it became known. Forming in the Bay of Biscay north of Spain and sweeping up across the country, it brought gusts of up to 185km/h (115mph) and sustained winds of more than 80km/h (50mph) across the south-east. The passage of the storm's warm front increased temperatures by up to 10°C, while barometric pressure fell to 951 millibars. It was the worst storm to have hit southern England and northern France in almost 300 years.

Forecasters had seen it coming. Five days earlier, the BBC's farmers' forecast warned that the weather would be "becoming very windy later in the week". By the middle of the week, however, the computer models that meteorologists use to make their predictions had ▶



LEFT: **The Sealink ferry *Hengist* remained beached for a week after the 1987 storm, and it took four months to repair**

become more uncertain. Shipping forecasts continued to warn of dangerous weather, but the inland forecasts cautioned of rain rather than winds. On the lunchtime news, weather presenter Michael Fish issued a now infamous proclamation that there would be no hurricane, and by the time most people went to bed, no warnings of unusually strong winds had been issued on TV or radio. As the night continued, however, the storm grew stronger and stronger. Meteorologists began to realise what was happening and issued ever-worsening alerts to emergency services and the government. At 10:35pm on 15 October, Force 10 gales over the channel were forecast. At 1:40am on 16 October, warnings of Force 11 were issued. The military was notified that its assistance may be required to deal with the storm's consequences.

So why was this particular storm so damaging? "One thing people talk about when they remember the storm was just how warm it was that night," says Dr Pete Inness, a meteorologist at the University of Reading. "The subtropical air mass sitting in the middle of the storm provided a huge amount of heat energy to spin the storm up."

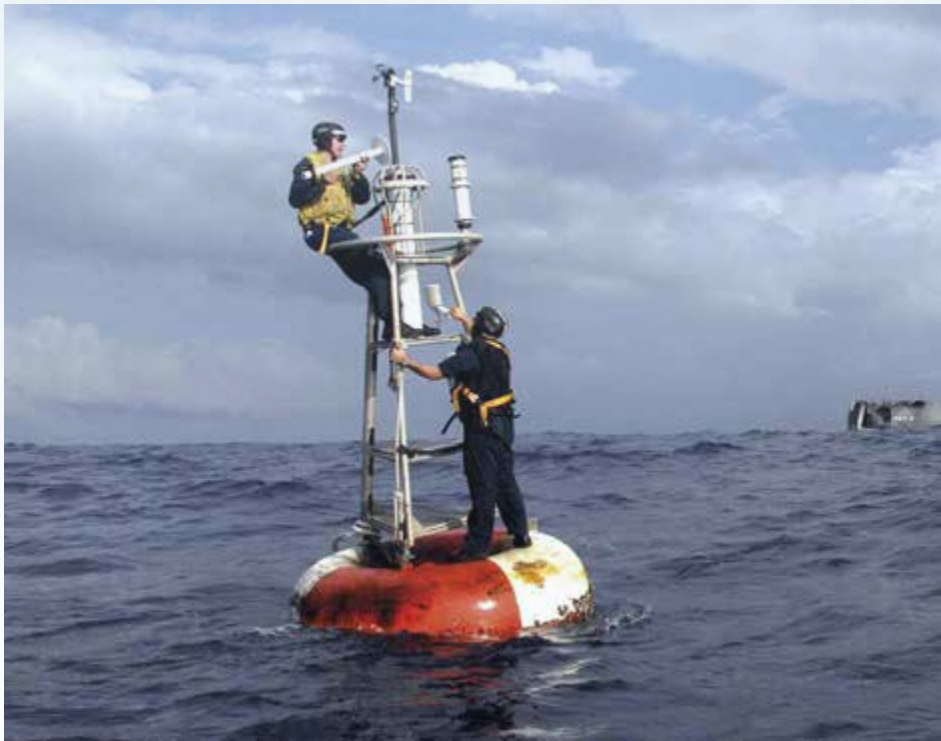
"There was also a very small feature developed within it, which we today call a sting jet, but was unknown to meteorologists in 1987," adds Mel Harrowsmith, head of civil contingencies at the Met Office. "A sting jet is, effectively, a small core of very strong winds, and they tend to happen towards the back end of a storm. So you get this very narrow, very strong core of wind that touches down on the ground and can cause a lot of devastation."

VIRTUAL WEATHER

Computer simulations of the atmosphere work in pretty much the same way today as they did back in 1987, and it's a three-step process. The first step is to collect data from meteorological stations on the ground, buoys in the ocean, weather balloons in the sky and satellites up in orbit. This can tell us what the state of the atmosphere is at any given time.

That data is then plugged into the computer model itself – a set of equations that reflect how air and water (the chief components of weather) behave under different circumstances. Hot air tends to rise over cold air, for example, and holds more water vapour. But as hot air rises it cools, and the water vapour condenses out into water droplets – just like on your mirror when you take a shower. That's how a cloud is made.

Finally, to get a forecast, the atmosphere is split up into a series of 'boxes'. Each box is given data from real-world observations and then allowed to develop according to the equations defined in step two. By seeing what happens in those different boxes over time, we get a weather forecast.



BELOW: **Buoys can help gather data on weather conditions at sea. Here, members of the US Navy adjust an NOAA weather buoy**

LEFT: Around 15 million trees were uprooted during the storm, including historic specimens at Kew Gardens and Hyde Park

"On the lunchtime news, Michael Fish issued a now infamous proclamation that there would be no hurricane, and by the time most people went to bed, no warnings had been issued"

The reason why forecasts can go wrong is the potential for mistakes in all three of these stages. In the first stage, we might not collect enough data: it's impossible to know the exact weather in every part of the globe – particularly over the ocean – so sometimes we have to make an educated guess on what numbers to put in. Plugging in numbers that are even slightly wrong will create an error that grows larger over time – just like the proverbial butterfly flapping its wings and eventually causing a hurricane. Meteorologists refer to this as 'chaos', and it's the main reason why forecasts get less accurate over time.

Even if you *did* have perfect data, you might not get a correct forecast because the equations aren't quite right. Meteorologists are constantly tweaking the physics of their models in response to the latest research, and the complexity of the atmosphere means that it's going to be a long time, if ever, before we can perfectly predict what the weather will do in every circumstance.

Finally, there are those boxes, which meteorologists refer to as the 'resolution' of the model. Think of them like the pixels of your laptop or smartphone: the more you have, the better the picture you get, but the more computing

PHOTOS: GETTY X2, BBC, NOAA

MICHAEL FISH VINDICATED

Why the weather forecaster was right after all

For many, the defining image of the Great Storm of 1987 was weather forecaster Michael Fish standing before the nation, promising there would be no hurricane. Someone had phoned the BBC earlier, he told viewers, with fears that one was on the way. "Well, if you're watching, don't worry, there isn't," he cheerfully said. A few hours later, the south-east of England was hit by the worst weather it had seen in almost 300 years

In subsequent days, as the damage was assessed, newspapers were filled with vitriol for Fish and the Met Office's perceived failure to get the forecast right. The Met Office admitted that its radio and TV bulletins had predominantly warned of rainfall rather than strong winds, and conducted an internal investigation which resulted in improved weather data collection in the northern Atlantic and a change in how severe weather warnings were issued.

Fish, however, stuck to his guns, pointing out that he'd followed up his reassurance with warnings that the weather would become very windy, and claiming that his hurricane comments referred to a storm that had recently hit Florida. It was a fair defence: the term 'hurricane' refers to *tropical* cyclones, not those that originate outside the tropics, as the Great Storm did. While wind speeds reached a level on the Beaufort scale labelled 'hurricane force', the Great Storm was never a hurricane. Fish was effectively right, but it mattered little: his name was forever associated with embarrassingly incorrect predictions.

power it takes to run them all at the same time. The same is true for weather models. This may be why the Great Storm of 1987 was so poorly forecast. "The boxes back then were about 150km by 150km," Harrowsmith says. "So if you have a small feature inside that box, the model cannot see it." The sting jet that made the storm particularly damaging was about 50km across, making it impossible for the model to take it into account.

ON THE UP

Since 1987, meteorologists have made substantial progress in all three areas of weather modelling, making forecasts far more reliable. "Our four-day forecast now is as accurate as our one-day forecast was 30 years ago," says Harrowsmith.

Some of that progress is down to increased supercomputing power. In 1982, the Met Office computers could handle 200 million calculations per second. In 1997, that figure was one trillion calculations per second, and earlier this year, the Met Office installed a new supercomputer capable of a stunning 14 quadrillion (that's 14 with 15 zeros after it) calculations per second.

But that's not all. We now have access to more weather observations, chiefly due to improvements in satellite and radar technology. The Met Office is in the middle of upgrading its radar network to be able to see not only where it's raining but also the size and shape of raindrops. This will help forecasters to differentiate between rain and snow – revealing whether that oncoming storm is a downpour or a blizzard.

We also have much more data from the Atlantic. "As a result of the Great Storm, the Met Office realised they didn't have enough observations over the ocean," says Dr Hannah Christensen at the US National Center for Atmospheric Research. "So they set up a lot more observational buoys out to the west and south, to fill in some of the gaps." Plus, new techniques like ensemble forecasting – where several forecasts are run at the same time with slightly different starting data – can give us an idea of how certain a forecast is. If all the models still come up with the same forecast, meteorologists can be more sure it's correct.

ARE WE GETTING MORE HURRICANES?

Dr Dann Mitchell,
climate scientist at the University of Bristol

In the Atlantic basin, the hurricane season normally lasts from June to November, peaking in September. The fact that we've seen eight hurricanes so far this year [as of 25 September] is markedly out of the ordinary – the average per season is six. However, perhaps more profound is the sheer number of strong hurricanes: this year was the first time in recorded US history that three Category 4+ hurricanes had made landfall in a single season. But whatever the remainder of the season brings, it's unlikely to be as active as the famous 2005 season. This saw Katrina, one of 15 hurricanes that year, devastate the US coastline and left much of New Orleans underwater.

Is there a link with climate change?

We know that a warmer atmosphere can hold more rain than a cooler atmosphere, so the downpour over Texas during Hurricane Harvey may have been worsened by climate change. We also know that hurricanes get their energy from the heat in oceans, so warmer oceans are theorised to lead to stronger hurricanes, although not necessarily to a change in the number of storms. But it's too early to say for sure whether the strong hurricanes we've been seeing recently are a result of climate change. To know this, we need to see a trend over a longer period, so time will tell. We're more sure, however, that climate change will worsen the impact of any storm surges caused by a hurricane's strong winds. With sea levels rising, storm surges can make it further inland, potentially leading to more widespread flooding.

Are we getting better at predicting hurricanes?

The hurricane path is perhaps the most important part of a forecast because you need to prepare when a hurricane's on its way. This is especially true if the system is travelling over low-lying islands, where storm surges can be devastating. Due to these risks, the US has invested heavily in predictive research, and now a reasonable forecast of a hurricane's path can be made three to five days ahead of time. A day before the hurricane hits, we can forecast its centre to within about 64km (40 miles). It was remarkable how close to the forecast Hurricane Irma came, and this undoubtedly saved lives.

ABOVE: **Forecasting is more accurate than ever, and the public can now get probabilities of poor weather**

LEFT: **When Hurricane Irma battered the Caribbean, meteorologists predicted the path of the storm with pretty good accuracy**

On the subject of uncertainty, one of the biggest changes for forecasters over the last three decades has been in the way that a forecast is communicated. Where once we were told it was going to rain, for example, we're now told there is a 60 per cent chance of rain. "For a long time the Met Office was reluctant to put out probabilistic information, and some of their reluctance came from the idea that the public wouldn't know how to use the information," says Christensen.

Different weather forecasting services use probabilities in different ways, but the Met Office explains on its website that its probabilities indicate how likely it is that precipitation will fall at some point during a specified period in a specified location. So a 70 per cent chance of rain in Scotland, for example, means that there's a seven-in-ten chance that some rain will fall anywhere north of the border. "If you have the communication channels to present those uncertainties, this extra information can help people to make decisions to protect themselves and their property," says Harrowsmith.

FUTURE FORECASTING

With continued improvements in computer power and our understanding of atmospheric physics, there's little doubt that our forecasts will also continue to improve. Inness says that some meteorologists are investigating automated rocket- or drone-launching buoys that could gather data on developing systems across the Atlantic. "You wouldn't use them every day," he says, "but they could come in handy if you knew there was a weather system in that area and were particularly uncertain about how it was going to develop. It's not fantasy by any means."

Meanwhile, a number of meteorologists are investigating the potential for artificial intelligence and machine learning to improve forecasts, by using past weather data to learn from inaccurate forecasts and make predictions about future weather patterns. "At the moment it seems to be in a very exploratory phase," says Christensen, "but there are results coming out which show that AI has the potential to help us process our enormous amount of observations to improve our simulations of the atmosphere."

But the better we get at forecasting, the harder it is to tease out further improvements – and the more demanding the audience gets. "These days, we'll do a 10-day forecast and we can predict that timescale with reasonable accuracy," says Rebekah LaBar, a consultant meteorologist for MetraWeather in New Zealand. "But there are always people that ask us: what's the coming summer going to be like? How many hot days are we going to have?"

Ultimately, there'll probably never be such a thing as a perfect weather forecast. No matter how good our models and how powerful our supercomputers, chaos means that even tiny mistakes in our observations will grow out of control over time, causing some degree of uncertainty in our predictions. But as atmospheric science continues to progress, a mistake on the scale of the Great Storm is looking increasingly like a thing of the past. Storm clouds today rarely take us by surprise. But it's always worth packing a raincoat, just in case.

"A number of meteorologists are investigating the potential for artificial intelligence and machine learning to improve forecasts"

A radome, seen here on top of a weather radar, protects the sensitive antenna from bad weather

PHOTO: GETTY, ALAMY, LARS COMMUNICATIONS

Duncan Geere is a freelance science and technology journalist based in Gothenburg, Sweden.

SHINE A LIGHT ON MEMORY

Optogenetics, a branch of science in which neurons are genetically modified to respond to light, is helping scientists to discover more about the brain, mental disorders and memory.

HOW DO WE KNOW...

HOW MEMORY WORKS?

Memories are what make us human, and now we're finally beginning to understand where, and how, they form

WORDS: **HELEN THOMSON**

Without memories, we'd be lost. They're the threads that hold our lives together, connecting who we were to who we are. But we've only recently pieced together the extraordinary brain science behind them – a story that takes in amnesiacs, mind palaces and ghostly carnivals.

One of our first analogies for understanding memory comes from Ancient Greece, where Plato likened memories to etchings on a wax tablet, and his favourite student, Aristotle, continued to use this in his own writings. Forgetfulness, said Aristotle, occurred in childhood because the wax was too soft, and in the elderly because it was too hard. For him, memories were not located in the brain, but throughout the body. He thought that the brain was present merely to cool the hot heart – the seat of our soul.

A tendency to favour the heart over the brain continued for centuries – in part because of the Church's ban on dissecting the human brain. In fact, it wasn't until the 17th Century that people began to realise that the brain had any capacity for thought at all.

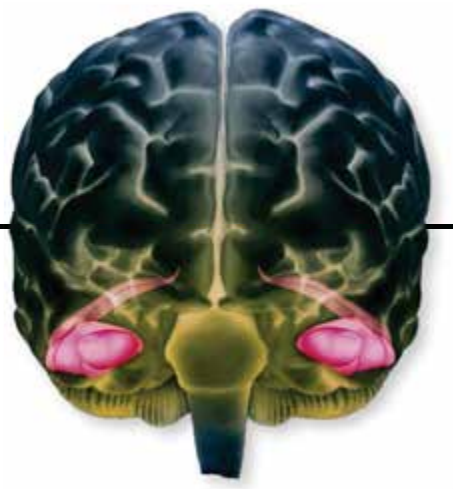
It was German philosopher Hermann Ebbinghaus who pioneered the first scientific study of memory in the late 19th Century. He cared less for where memories lay in the brain, and more for how memory worked. In his most famous experiments, he created a list of more than 2,000 nonsense words, such as 'kaf' or 'nid', which he proceeded to memorise and then tried to recall over time. Ebbinghaus discovered that we tend to forget in an exponential way – that is, we forget a lot soon after learning, and then we forget in a slower manner over time.

He also classified memory into three types: sensory, short-term and long-term – labels that are still used today.

Sensory memory is the first kind of memory that enters your brain: it lasts for a split second. The touch of your clothes against your skin, the smell of a bonfire. Unless we attend to that memory, it disappears for good. Give it some thought, however, and you will nudge it into your short-term memory. You use this all the time without realising. For instance, you can only understand what happens at the end of this sentence because you remember what happened at the beginning. Our short-term memory is said to have a ➤

Aristotle, painted by Jean-Louis Bézard, in the 19th-Century book *Vies des Savants Illustres*

PHOTO: SPUTNIK ANIMATION/MCGOVERN INSTITUTE/ED BOYDEN/MIT, SCIENCE PHOTO LIBRARY



The brain's hippocampus, highlighted in pink, is so-called because it looks like a seahorse (the Greek word for seahorse is 'hippocampus')

capacity for about seven items, which can be held in the mind for around 15 to 30 seconds. Rehearsing these items would be a way to transfer them into your long-term memory – our seemingly limitless warehouse for storing memories for the long haul.

TOTAL RECALL

Over the following decades, others continued to advance our understanding of memory. One of the most influential was a British psychologist called Frederic Bartlett. In 1914, he performed a series of experiments in which he asked students to read a story and repeat it back from memory. By analysing how the story transformed over days, months and years, he advanced the (now proven) theory that memories are imperfect reconstructions of events. He said we actually only remember a small part of the original observation, and fill in the gaps with cultural references and personal knowledge.

But despite a growing recognition of how human memory worked, many questions remained. Where are memories stored? What does a memory look like? Those were questions that the American psychologist Karl Lashley spent his whole career trying to answer. His most important experiments involved searching for traces of memory within specific areas of the rat's cerebral cortex – the folded, outer layer of the brain that plays a role in cognition, sensory perception, decision making, and a whole host of other key functions. From 1935 onwards, he systematically damaged specific areas of the cortex before or after a rat was trained to find its way out of a maze. But no matter which part of the brain was removed, the rats continued to remember how to exit the maze better than rats who had never been trained in the first place. Lashley concluded that our ability to learn and remember must be distributed across many parts of the brain instead of lying within a single region.

One particular patient proved key to this idea: a young man called Henry Molaison. Having suffered severe epileptic seizures for most of his life, Molaison agreed to a drastic experimental treatment. In 1953, surgeons drilled holes into his brain and sucked out the areas responsible for the seizures – a seahorse-shaped region on either side of the brain called the hippocampus. The operation was a success in that it largely cured his seizures, but Molaison was left with profound amnesia, unable to create new long-term memories.

However, Molaison *could* remember most of his past up until a few years before the operation. It was later discovered that he could also form procedural memories, a type of long-term memory responsible for knowing how to do something, like riding a bike. Molaison's memory troubles

Even when rats have particular parts of their brain removed, they can still navigate a maze they've previously experienced, suggesting that several parts of the brain are involved in memory

GLOSSARY

Hippocampus
An area of the brain that is vital to forming different kinds of memories.

Neuron
A cell that is uniquely suited to passing messages around the brain in the form of electrical activity. Our brains contain some 86 billion of them.

Neurotransmitter
A chemical messenger that is released at the end of a neuron by the arrival of an electrical impulse. Neurotransmitters diffuse across the gap and make nearby neurons more or less likely to fire their own electrical impulse.

Semantic memory
A type of long-term memory of ideas and facts that is not drawn from personal experience, such as the name of a colour.

Synapse
The gap between two neurons, which allows activity to flow from one cell to the next. Changes in these structures are integral to memory and learning.

PHOTOS: GETTY, SCIENCE PHOTO LIBRARY

TIMELINE: A HISTORY OF MEMORY

Scientists have been unravelling the mystery of memory for centuries...

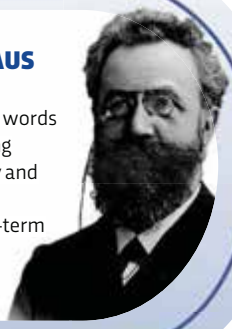
500 BC

500 BC
Ancient Greek poet Simonides of Ceos develops what is now known as the method of loci: a memory technique that world memory champions can use to remember pi to 70,000 digits.

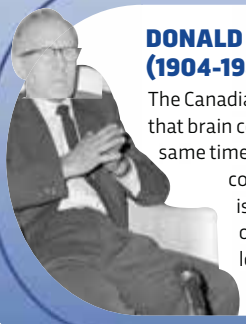
300 BC

300 BC
Philosophers Plato and Aristotle put forward the first theories of memory, describing it as something akin to etchings on a wax tablet.

HERMANN EBBINGHAUS (1850-1909)
Created a series of nonsense words that provided a way of testing different aspects of memory and forgetting, leading to early definitions of sensory, short-term and long-term memory.



1906



DONALD HEBB (1904-1985)
The Canadian psychologist proposed that brain cells that are active at the same time form new and stronger connections – a theory that is now known to underlie our ability to create long-term memories.

1906
Physicians Santiago Ramón y Cajal and Camillo Golgi share a Nobel Prize in Physiology or Medicine for their work on staining techniques that provided the first clear images of individual neurons.

WILDER PENFIELD (1891-1976)
Used electrical currents to stimulate the brain during surgery while his patients were awake. He discovered that you could evoke a memory merely by stimulating parts of the cortex.

1990s

HENRY MOLAISON (1926-2008)
After having both sides of his hippocampus removed, Molaison experienced profound amnesia. He became one of neuroscience's most studied individuals, providing key insights into where memories are stored in the brain.

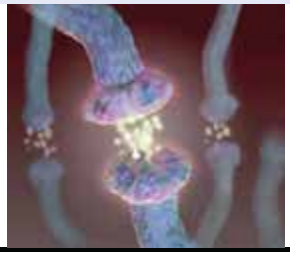
1990s
Throughout the 1990s, Elizabeth Loftus and her colleagues demonstrate the malleability of memory, specifically how false memories can be implanted in our minds.

ELEANOR MAGUIRE (1970-)
In 2002, this neuroscientist scanned the world's best memorisers and found their brains did not differ from anyone else's. They were better at remembering because they used a mnemonic device called the method of loci.

2017
Researchers use optogenetics to discover that long-term memories are created in the brain at the same time as short-term memories, overturning a decades-old theory of how long-term memories form.

2017

PHOTOS: UNIVERSITY OF BRITISH COLUMBIA, UCL, GETTY X2, ALAMY, SCIENCE PHOTO LIBRARY X2, JENNI OGDEN



Neurotransmitters send a signal across a synapse, which is the gap between two neurons

proved that the hippocampus was vital in creating most new memories, but that the memories themselves were stored elsewhere in the brain. Researchers, including neuroscientist Prof Suzanne Corkin, continued to test Molaison regularly over the next 46 years – although for Molaison, each day they spoke was like the first. "It's a funny thing," Molaison told Corkin. "You just live and learn. I'm living and you're learning."

MAKING CONNECTIONS

Although Molaison was instrumental in convincing the research community that memory was not the responsibility of one sole region of the brain, it did not answer the question of how a memory was formed. Back in 1906, Camillo Golgi and Santiago Ramón y Cajal had been jointly awarded a Nobel Prize for advances in cell-staining techniques that demonstrated the anatomy of a neuron. Thanks to their work, scientists knew there were millions of neurons in the brain that pass messages to each other in the form of electrical impulses. When an impulse reaches the end of one neuron, it causes the release of chemical messengers called neurotransmitters, which pass across the gap, or synapse, and latch onto a neighbouring neuron. This makes the second neuron more or less likely to fire its own impulse. But how these neurons formed long-term memories was still a mystery.

That remained the case until 1949, when Donald Hebb published one of the most influential theories of neuroscience in the last century. He wrote that any two brain cells that are repeatedly active at the same time will tend to become 'associated'. Their anatomy and physiology will change so that they form new connections or strengthen existing ones. The activity in one, he said, will subsequently facilitate activity in the other. You'll often find this summarised as "neurons that fire together, wire together."

Simply put, if two concepts, say the smell of a rose and its name, repeatedly stimulate their respecting neurons in the brain at the same time, those neurons will change shape and strengthen that connection. Neurons associated with the smell of a rose will now more likely stimulate neurons responsible for its name. This, said Hebb, is the process that underlies the storage of long-term memories. Such memories endure because they are now a unique part of your neuronal architecture. The more they are recalled, the stronger and more permanent the memory becomes.

Around the same time, Canadian surgeon Wilder Penfield demonstrated how stimulating parts of the cortex could evoke a memory. He was operating on people with epilepsy who were awake during the surgery. While operating on one woman, he stimulated an area overlaying the hippocampus, within the cortex. His patient spoke: "I think I hear a mother calling her little boy somewhere, it seems to be something that happened years ago in the neighbourhood where I live."

Penfield stimulated the spot again, and once more the mother's voice cried out. He moved the stimulus a little to the left, and suddenly the woman heard more voices. It was late at night, she said, and they were coming from a carnival. "There are lots of big wagons that they're using to haul in the animals". The tiny jolts of activity applied by Penfield seemed to be bringing to life long-forgotten memories – like reaching into a dusty album and picking a photo at random.

Recalling memories is a mysterious process that is still not fully understood. However, thanks to Prof Elizabeth Loftus, now at the University of Washington, we know that our recall is not always accurate. In the 1990s, she demonstrated that false memories could be implanted in people's minds. She convinced people of fake chokings, near drownings, even demonic possessions. She showed that tiredness, drugs and low IQ could all influence how likely someone is to be at risk of forming false memories. Her work revealed

THE KEY DISCOVERY

Scientist: Santiago Ramón y Cajal

Date: 1889

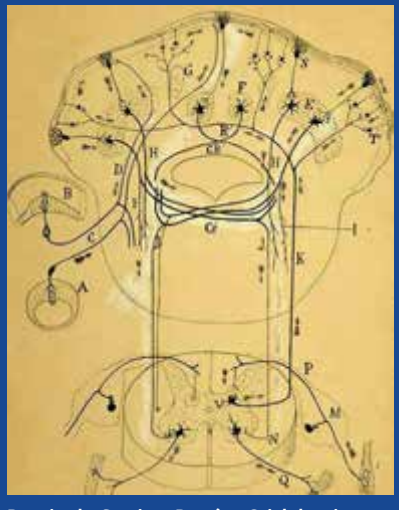
Discovery: The precise physical structure of a brain cell – the anatomical basis for memory

The jelly-like matter of the brain fascinated Spanish pathologist Santiago Ramón y Cajal. In 1877, he saved up all the money he had earned as a medical officer in the Spanish army to buy an old microscope.

For several years he attempted to use the microscope to study and catalogue the tiny structures within the brain, but they were impossible to see clearly. He wanted to solve the fierce, ongoing debate as to whether the brain was made up of individual cells, or whether these cells were all continuously interconnected.

In 1873, the Italian physician, Camillo Golgi, developed a staining technique using silver nitrate that allowed a much clearer view of brain tissue. For years, Cajal worked on refining this technique. As a passionate artist, he drew everything he saw, and in 1889, he presented his findings to the Congress of the German Anatomical Society at the University of Berlin.

Each stained brain cell stood out perfectly. Its complexity could be seen in detail, showing there was no direct physical connection between each cell, and settling the long-running debate. Cajal's pictures are still used in neuroscience today to demonstrate the precise architecture of the brain that underlies memory, and all other aspects of human thought.



Drawing by Santiago Ramón y Cajal showing connections in the brain's cerebellum

PHOTOS: SCIENCE PHOTO LIBRARY X2

By stimulating patients' brains, neuroscientist Wilder Penfield (pictured) resurrected long-lost memories

something quite extraordinary: that our memories, once formed, are not fixed. Each time we retrieve a memory, we strengthen the neural pathways that have created it, and in doing so, reinforce and consolidate that memory so that it becomes lodged more permanently in our minds. But for a short time during this retrieval process, our memory becomes malleable – we are able to reshape it and, sometimes, contaminate it.

MEMORY, WHERE ART THOU?

With advancing imaging techniques, research has focused once again on pinpointing where in the brain memories are stored. We now know that the hippocampus springs into action to glue different aspects of a single memory together. Indeed, when people attempt to learn new associations and recall them later, those whose hippocampus generated the most activity while learning the associations are best at recalling them in the future. It's as if they glued them together better in the first place.

By putting all the pieces of the puzzle together, researchers thought they had a pretty good theory of memory: they surmised that all incoming information is briefly processed in the cortex, before converging on the hippocampus. The hippocampus sorts through the new information, deciding how 'important' it is (in essence, does it look like something worth remembering?), and then, if necessary, encoding it in the brain by forming new synapses. Over time, the neurons that represent this memory will migrate into the cortex for long-term storage, their connections being strengthened each time we access the memory.

However, advanced methods for recording and manipulating brain activity have recently turned that theory on its head. Earlier this year, researchers at the Massachusetts Institute of Technology, led by Takashi Kitamura, showed that short- and long-term memories are actually formed simultaneously.

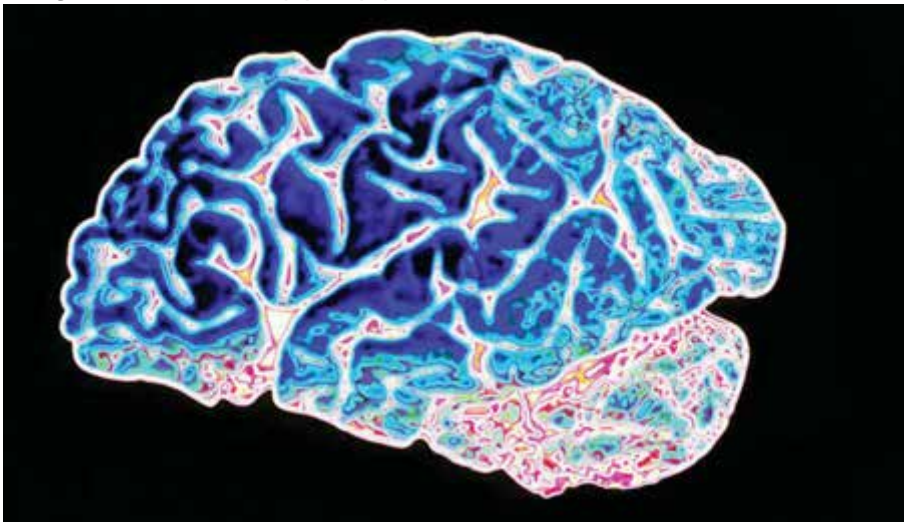
Kitamura's team used new techniques that involved optogenetics, which is a way of turning cells on and off using light, together with labelling individual memory cells. The team trained mice to fear a particular chamber by giving them a small electric shock when they entered it. Immediately after the training, the researchers were able to see memories of the shock forming in both the hippocampus and the prefrontal cortex, an area just behind the forehead. However, the memory cells in the prefrontal cortex lay silent. A trace of the memory was definitely there, though – when the team stimulated these cells artificially, the mouse would freeze, just as it did when the hippocampal memory cells were active and when the mouse naturally encountered the chamber.

Rather than the memory gradually migrating from the hippocampus to the cortex, it appeared it was already there. Over two weeks, the cortex memory cells changed shape and activity and eventually became active by themselves when the mice encountered the chamber, at which point the hippocampal memory cells became silent.

Such sophisticated methods for analysing the human brain will continue to help us understand healthy memory, as well as what happens when it is ravaged by disease. Alzheimer's remains the leading cause of dementia, affecting more than half a million people in the UK. The disease destroys the vital connections between neurons, leading to memory loss and confusion. Despite our best efforts, there is still no cure.

There are, however, ways in which you can improve your memory. Research by Prof Eleanor Maguire at University College London has shown that the brains of the world's best memorisers aren't any different to anyone else's anatomically: the memory champs just make use of an ancient technique called the 'method of loci'. In order to remember a large number of items, place them around a 'mind palace'. This can be any location that you know well. To recall the items, you just retrace your route and pick them up. It's a trick that makes anything easier to recall at a later date. Try it for yourself: it turns out that anyone can be a super memoriser.

This computer-enhanced image shows a brain with Alzheimer's. The widened areas between the folds are caused by wasting of the brain tissue – a classic physical symptom of the disease



Helen Thomson is a science journalist and editor, with a particular interest in the brain. Her book, *Unthinkable: An Extraordinary Journey Through The World's Strangest Brains* (£16.99, John Murray), is out next year.

DISCOVER MORE

Listen to an episode of *All In The Mind* about neuroscience, psychosis in prisons, and Henry Molaison at **bit.ly/molaison**

PHOTOS: MCGILL UNIVERSITY, SCIENCE PHOTO LIBRARY

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PHOTO: E-DAVID/OLIVER DEUSSEN

CAN ARTIFICIAL INTELLIGENCE CREATE GREAT ART?

Autonomous programs have started to produce paintings that match human talent. So should artists hang up their paintbrushes for good?

WORDS: **DINSA SACHAN**

At this year's Sonar+D, a glittering arts-tech event in Barcelona, enthusiasts lined up to get a glimpse of the Spanish artist Albert Barqué-Duran's creative process as he fervently painted a mural. It was a typical sight at the arts event, but the painting was no ordinary artwork.

Next to the mural, a computer screen showed a nude, voluptuous woman, her face slightly blurred out. The painting had been conjured up by an artificial intelligence-powered program. Barqué-Duran was essentially transferring the program's 'imagination' onto a wall.

So, artificial intelligence (AI) has entered the world of art, but people are curious to know: can AI create artistic masterpieces? Can an AI be the next Vincent van Gogh or Rembrandt?

The field of AI art seems to have emerged out of nowhere, but it has actually been years in the ▶

"The program even reflected on its output, by providing commentary on the portrait"

making. "Artworks created with help from machine learning and artificial intelligence fall under the broader category of new media art, a genre that has been active for several decades," says Ali Momeni, associate professor of art at Carnegie Mellon University, Pennsylvania. The first AI artist was AARON, which was created by British-born artist Harold Cohen. It produced paintings in many styles, from the 1970s until Cohen's death in 2016.

But the last few years have seen an explosion of projects. Momeni says that free software resources such as Google's TensorFlow and hardware advances of the gaming industry have played a key role in propelling the field of AI art. TensorFlow is a free software library that developers can use to create artificial intelligence programs. Graphic processing units (present on graphic cards) are crucial for many computer games. But thanks to their fast processing speeds they also come in handy for making digital art.

Add to that winning mix, the ready availability of datasets. "Software tools rely on an enormous body of pre-analysed data – such as ImageNet for images – based on which new things could be classified or generated, and these datasets were simply not available a decade ago," Momeni explains.

THE RISE OF AI ARTISTS

The program that created the nude at Sonar+D was trained by German artist Mario Klingemann. At the heart of Klingemann's work are artificial intelligence algorithms called Generative Adversarial Networks, or GANs. A GAN is basically a type of neural network, and a neural network is an algorithm that mimics how the brain works. Klingemann uses a combination of several different neural networks to achieve intricately detailed paintings. First, he has to prepare a training set that consists of thousands of example images showing humans in a variety of poses off the internet. Next, he uses a neural network that is able to extract stick figures from these images. Then a second neural network – the GAN – is trained using this dataset. The GAN is run through sets of stick figures and the original photo from which they were derived. After processing thousands of such pairs it learns how stick figures can be translated to humans in various poses. The GAN makes a lot of mistakes because it is difficult for it to master the human form. "But for me that is exactly the interesting aspect of working with these neural networks since it leaves a lot of space for uncertainty and surprise," says Klingemann.

For artists like Klingemann, AI is about experimenting with art and learning about machine creativity. "Right now, we mostly see visual examples where the networks learn to transform one image into another, but the same principle could be applied to audio, text or any other kind of data." Klingemann says that businesses will start to use AI art when it becomes cheap to produce. For example, retailers could use AI to generate original designs for wall art in shops or restaurants, then mass produce them on canvas.

And then there is The Painting Fool: a highly complex program from Prof Simon Colton, a computer scientist at Goldsmiths College, London. Colton likes to consider The Painting Fool an 'aspiring' AI artist. Different AI techniques, including machine learning and natural language processing, have been used to give The Painting Fool the ability to create original art. Machine learning technology uses algorithms – basic sets of rules to solve problems – that can learn to get better on their own. In the world of art, that generally means creating

BELOW: **This chair image, named *Uneasy*, is one of The Painting Fool's earlier pieces**

WHAT IS MACHINE LEARNING?

Machine learning is a branch of artificial intelligence that borrows heavily from other fields such as statistics, mathematics, physics and theoretical computer science. Machine-learning algorithms enable computers to perform tasks without human intervention. With this technique, machines can be taught to make their own programs. Every time you ask your virtual assistant Alexa or Siri to perform a specific task, that's machine learning in action.

More complex uses of machine learning include image classification. For example, Adobe has developed a feature called Smart Tags for its program Experience Manager. It can add tags to images automatically. For example, to an image of the Washington Memorial, it would slap tags such as 'architecture', 'memorial', and 'Washington Memorial'. If someone searched for architecture images on their system, the Washington Memorial photo would show up. AI art tools developed by Mario Klingemann, Dan Ventura and Simon Colton all make use of machine learning.

PHOTOS: THE PAINTING FOOL, HANK MORGAN/SCINETPHOTOS.COM, ALBERT BARQUÉ-DURAN/SONAR+D

British artist Harold Cohen created a painting machine controlled by his AI program AARON

My Artificial Muse is programmed with stick figures, which it uses to create nudes. At this year's Sonar+D exhibition, artist Albert Barqué-Duran recreated one of My Artificial Muse's designs as a mural (pictured)

machines that don't need to be programmed in a detailed manner every time you want them to produce an artwork. Natural language processing, on the other hand, is a type of AI technique that allows computers to understand human language and apply them to their tasks – something that normal computers are unable to do.

The Painting Fool's art has been exhibited in museums and galleries across the world. At an exhibition in Paris in 2013, the program enthralled the audience by creating their portraits. To stimulate the program's mood, the researchers provided it with a newspaper. "If it read 10 articles of a very happy nature – somebody won a football cup, somebody gave birth to triplets – then it would be in a good mood," says Colton.

Based on its mood, the program chose adjectives. For example: happy. If it was happy, it requested the subject to smile. If it was sad, it asked the subjects to simply go away. The program even reflected on its output, by explaining why it was happy or unhappy with the finished result.

Some of The Painting Fool's ability has been borrowed from Digital Artist Communicating Intent (DARCI), the brainchild of Prof Dan Ventura at Brigham Young University in Utah. DARCI has been trained to perceive pictures just as humans do. "It looks at these pictures and tries to make sense of these shapes and forms and makes something of its own," says Ventura. Ventura's team ran the program through thousands of images that humans had tagged with adjectives. This means that DARCI can look at a picture and ascertain whether the picture is happy, sad or scary.

IS AI THE FUTURE OF ART?

The Painting Fool and DARCI seem to demonstrate a level of independence, and that's why their creators call them artists. But it does beg the question: do we really need them? Colton argues that a product like The Painting Fool helps the arts. It has made more than a thousand portraits, and some of its subjects later hired professional artists to do their portraits. "It helps people realise the value of creativity in their lives," says Colton. "It democratises the arts by making available to non-rich people the kind of things rich people take for granted."

While AI might be threatening jobs in transport and information technology, it's only natural for artists to be concerned about this wave of art-generating programs. "We're not talking about making art that will rival what humans do. It's mostly about machine learning right now," says Marian Mazzone, professor of modern and

RIGHT: **The Next Rembrandt project involved scanning paintings by Rembrandt, to create a completely original piece of Rembrandt-like art using AI techniques and 3D printing**

"We're not talking about making art that will rival what humans do"

A HISTORY OF AI ART

1970s
AARON

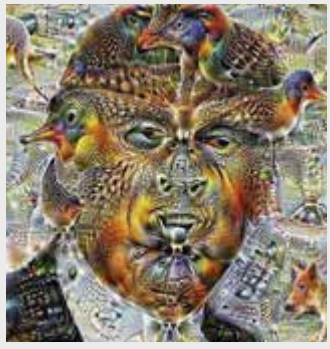
This computer, invented by professor and artist Harold Cohen, created paintings autonomously, starting in the early 1970s until Cohen's death last year.

2006
The Painting Fool

The brainchild of British computer scientist Simon Colton, this complex tool is capable of setting its mood and generating paintings based on how it feels. It can also reflect on the quality of its work and learn from its mistakes.

2010
DARCI

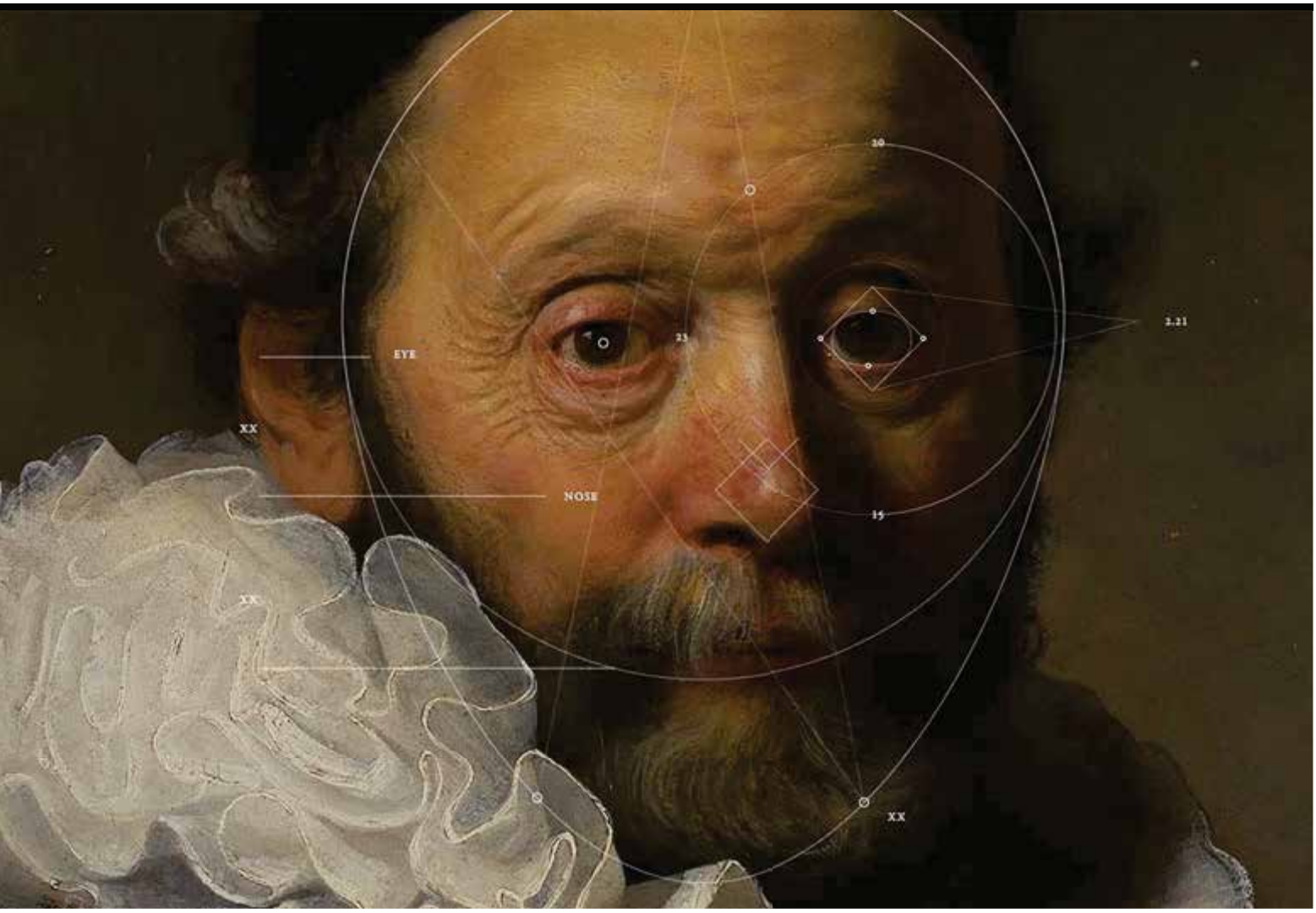
Developed by Dan Ventura, a computer scientist at Brigham Young University in Utah, DARCI can make sense of things like colour and texture in pictures and use them as inspiration for its own original painting-like images.



2015
Deep Dream Generator

Google's free program can take simple, everyday pictures and transform them into quirky, psychedelic ones. The tool inspired an entire generation of artists to experiment with AI art.

PHOTOS: HANK MORGAN/SCINETPHOTOS.COM, DEEP DREAM GENERATOR



PHOTOS: NEXT REMBRANDT X2, THE PAINTING FOOL, MATTY MO, ALBERT BARQUÉ-DURAN/SONAR+D

2016
The Next Rembrandt

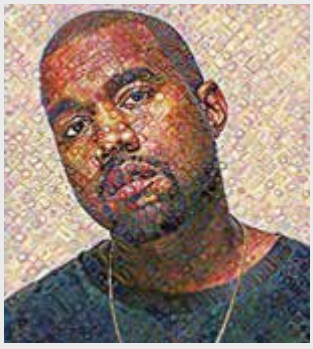
Researchers at advertising agency J Walter Thompson Amsterdam taught a computer to paint like Rembrandt using advanced AI techniques. The computer produced an original piece of art in Rembrandt's style.

2017
My Artificial Muse

German artist Mario Klingemann used an AI program to convert stick figures into paintings with human forms. Spanish artist Albert Barqué-Duran transferred the painting onto a mural.

2017
Creative Adversarial Networks

Researchers from Rutgers University reported an AI trained in different styles of art. It can create paintings in its own novel styles by deviating from conventional styles.



2017
Artificial Intelligence: The End Of Art As We Know It

Artist Matty Mo joined forces with hackers to design an AI to create portraits of people who could lose their jobs to AI.

contemporary art at the College of Charleston, South Carolina. Mazzone was part of a team that recently developed a special type of GAN that can crank out painting-like images in novel styles. Mazzone says that this GAN is comparable to human creativity. "The system is exposed to a number of other artists' works, and then develops its own works based on that knowledge," she says. "Decisions are made, elements are chosen, new combinations are tried. Human artists also learn from other artists and develop their own style over time."

Right now, a computer is unlikely to create a masterpiece like Pablo Picasso's *Guernica* or Leonardo da Vinci's *Mona Lisa*. Klingemann says the current quality of AI art is comparable to the blurry and unrealistic images of photography's early days. "But in 5 to 10 years, AI will definitely mimic what humans consider great art," he predicts. Yet even with improving technology, it might not be possible to get a truly creative AI. "That would mean that it is able to develop its own personality, taste and motivations autonomously," explains Klingemann. "Compelling storytelling – or even story understanding – is still an unsolved problem in AI and in my opinion it is one of the most important components from which you can then create everything else."

Humans use their life experiences to influence their art – something programs can't do. "If you think about Vincent van Gogh, his whole life story, his mental illness, struggle, all of it added up to making his work more of a masterpiece than what it would have been without all of that backstory," says Colton. "If a program painted those pictures, they would probably be immaterial."

So if there ever is a truly creative AI, would the art world accept its creations? "I'm not holding my breath," says Momeni. "In fact, I wouldn't be surprised if the art market had the absolute opposite response and retreated further into conservatism."

Dinsa Sachan is a New Delhi-based journalist who specialises in science, technology and culture.

BELOW: **Deep Dream can interpret a painting style and transfer it onto an uploaded image**

PHOTO: DEEP DREAM GENERATOR

BBC FOCUS

SCIENCE OF SOUND

AN IN-DEPTH LOOK AT THE HOTTEST TECH IN AUDIO

A new generation of audio technology is enhancing the music listening experience and making audio sound more realistic. From portable devices and digital-to-analogue converters, through to amplifiers and speaker systems, discover the kit that's delivering clarity of sound like never before. ***Take a look now – it will be music to your ears.***

MQA | audioquest

THE NEW SOUND OF MUSIC

*British company **MQA** believes streaming your music shouldn't mean you have to compromise on sound quality. Its breakthrough tech will give you studio-quality audio however you want to listen to your music*

Attitudes to digital audio are even more splintered today than when CD was introduced 35 years ago. While a lot of people love the quality of digital and the fact that it conveniently allows you to listen to music virtually anywhere, others like digital audio but consider CD inferior and lossily-compressed formats like MP3 even worse, preferring instead 'hi-res' digital with an increased sampling rate. Some people hate digital audio for what it's done to how we listen to music, how we value it, and how we remunerate the people who make it. And finally, many vinyl fans simply dislike its sound quality, believing something vital was lost in the switch from analogue, along with the tactile and visual pleasure that vinyl delivers.

Nobody could hope to reconcile these disparate views, but British outfit MQA Ltd is trying to square the convenience versus quality circle, with a new digital audio technology that has already gained significant traction in the music and audio industries.

MQA stands for Master Quality Authenticated. The name conveys its core aim, if not the means of achieving it: to deliver exactly the sound that was signed off in the mastering studio. It can't do this completely because the amplifiers and loudspeakers in the studio, not to mention the acoustics, will not be the same as in the listener's home. But it does ensure that the electrical signal to the amplifiers is the same.

MQA comprises two key elements. First, it implements proprietary technologies for 'folding' a hi-res digital audio signal into a base-rate one with a sampling frequency of either 44.1kHz (the same as CD) or 48kHz (as initially used in professional audio). MQA calls this process – which actually comprises two different

If digital audio had sounded this way from the outset, the analogue versus digital sound quality controversy would never have arisen

processes – 'music origami'. The object is to reduce the data rate required to stream a hi-res stereo file to about 1Mb/s, less than the data rate of CD audio (1.4112Mb/s). This is where MQA's solution to the convenience/quality dilemma lies – it delivers the sound quality of hi-res digital without the large file size or high bit-rate requirement.

But MQA goes further. It aims to improve on the sound quality of even hi-res digital audio by ensuring no more 'harm' is done to the source signal (the sound impinging on the recording microphone) than a few metres of air will do to the passage of sound. If digital audio had sounded this way from the outset, the whole digital sound quality controversy may never have arisen.

Encouraged by astonishing research findings into the human ear's ability to better the time/frequency resolution of engineers' electronic signal analysers, MQA puts the emphasis on time-domain rather than frequency-domain performance. It controls time-domain behaviour from one end of the signal chain to the other – from the recording microphone through to the output of the digital-to-analogue converter in your home.

But it's not the technology alone that has made MQA the digital audio encoding process that both audiophiles, and those more concerned with small file sizes and low bit-rates, can embrace. Bob Stuart, the creator of MQA, already well known in specialist audio circles as co-founder of Meridian Audio, has been tireless in promoting its benefits worldwide – a vital effort missing in the development of previous audio technologies. As a result, MQA is rapidly gaining momentum with increasing numbers of record companies, streaming services and hardware manufacturers that have already made the decision to support it.

HOW CAN YOU EXPERIENCE MQA?

Although MQA files will play anywhere, the full benefit of the technology is best heard when the music origami process is undone to restore the original sampling rate. This can be achieved by MQA decoding in either hardware or software. Streaming service Tidal currently offers MQA compatibility (with others including Deezer and Groovers+ set to follow suit), while MQA files can be played on the LG V30 smartphone, or personal audio players from Onkyo, Pioneer and Sony. MQA files can be played using more than a dozen makes of MQA-compatible network streamers, including Bluesound, or from your computer via an even larger number of compatible digital-to-analogue converters. The MQA-ready DragonFly Black and Red USB DACs from AudioQuest cost from just £89.

MQA audioquest

TO FIND OUT MORE

A full list of MQA's current partners is available at *mqa.co.uk*

HEAR AND NOW

Flare Audio founder Davies Roberts has spent years painstakingly researching the science of sound to develop earphones and speaker systems that eliminate distortion

For an audio technology company whose raison d'être is to deliver clean, distortion-free sound, Flare Audio sure is making a lot of noise. It's brought ultra-low distortion music to concerts, festivals and even London's historic Olympic Studio, helping to transform the renowned recording venue into a state-of-the-art, two-screen cinema.

Now big-hitters from the music industry, including Led Zeppelin's Jimmy Page, Jarvis Cocker and award-winning producer Tony Visconti, have been lining up to heap praise on Flare Audio's innovative equipment. The latest product to catch their attention is the Flares Pro wireless earphone range. Featuring Bluetooth 4.1 connectivity, they use Anti-Resonance technology to eliminate as much audio distortion as possible, and deliver uncorrupted sound that retains all of its definition.

Dual Jet and Acoustic Lens technology focusses sound directly onto the eardrum, while Grade 5 Titanium shells helps ensure listeners enjoy the purest sonic realism from their music. Add to that the clean, eye-catching designs and it's not hard to see why leading musicians have been endorsing them so enthusiastically.

"These are the best earphones ever! I mix on these. The detail, the clarity and low end are 'pinch me am I dreaming?' great."

Tony Visconti, Grammy award-winning producer (David Bowie, T-Rex, Iggy Pop)

'My Flares are THE most sonically responsive in-ears I have ever heard,' says Fun Lovin' Criminals frontman Huey Morgan. 'I mix on them with confidence and have never been disappointed... Simply the best sounding in-ear on the market.'

Not only have the engineers at Flare Audio re-designed the way sound is delivered, they have also revolutionised the way it is blocked, with their Isolate range of earplugs. Unlike other earplugs, which use plastic, foam and silicone to absorb sound, the Isolate models use aluminium and titanium that totally blocks unwanted, low-frequency noise.

TO FIND OUT MORE
visit *flareaudio.com*

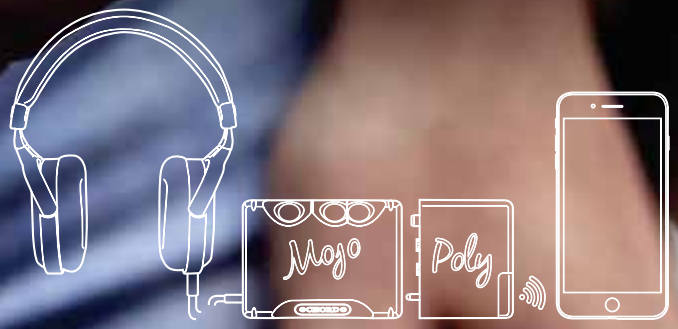
FLARE®
LONG LIVE EARS®

Turn your smartphone into a wireless high-res digital audio player

CHORD
Chord Electronics Ltd.

MADE IN THE UNITED KINGDOM

Combine the Poly streaming module with the multi-award-winning Mojo DAC/ headphone amp and effortlessly stream music from your devices both at home and on the go, wirelessly.



Poly

DESIGNED FOR Mojo
Made in the United Kingdom

#chordpoly

On sale 19th October from amazon.co.uk

discover more: chordmojo.com

- 9 hour battery life
- Bluetooth A2DP Connectivity
- WiFi 2.4gHz Connectivity
- Airplay Connectivity
- Micro SD Card Storage

THE FUTURE OF AUDIO

Sennheiser has been at the forefront of audio for over 70 years – and now, it's perfecting the art of tangle-free travel with its new wireless headsets

Sennheiser's story began back in 1945 when the family firm launched, quickly gaining a reputation for manufacturing cutting-edge audio solutions that were exactly what the customer wanted. Today, the Sennheiser family are still very much in control – with the third generation taking the reins of a company that has now become a world-wide organisation.

Remarkably, it's been 22 years since the landmark launch of Sennheiser's first set of ground-breaking, cable-free cans, and the legendary headphones manufacturer remains a true leader in audio evolution, style and sophistication.

Much of that evolution is thanks to Bluetooth technology; a secure way of exchanging wireless data amongst different devices. It derives its name from Harald Blåtand Gormsen, the Viking king with a gift for bringing people together, who united tribes from Denmark and Norway into a peaceful kingdom. And if you translate Blåtand, guess what? You get Bluetooth.

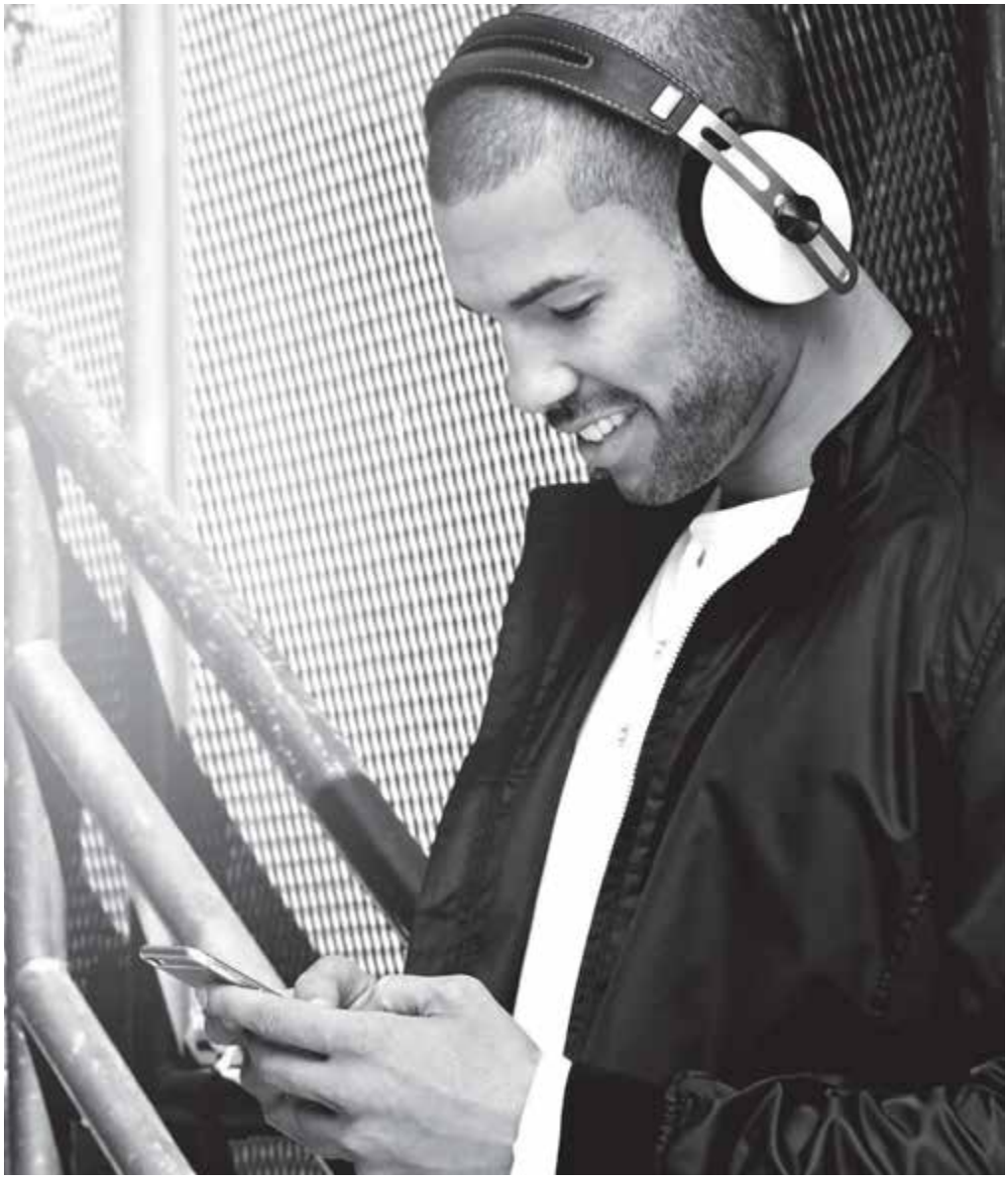
But back in the 90s, Bluetooth had a bit of a shaky start. Manufacturers keen to embrace this new technology, did so at the expense of developing the acoustics of their headphones. So audio quality suffered and Bluetooth developed a bit of a bad reputation.

When Sennheiser got on board, it realised the key to great audio quality was ensuring a stable connection between the source of the sound and the headphones. Achieving that meant an innovative redesign of the radio frequency components – but this became the company's stronghold for decades. For the first time, Bluetooth could deliver crystal clear sound, wirelessly.

Building on that rich heritage of invention, the German audio giant has now added Bluetooth-equipped versions to its premium MOMENTUM range, offering that signature high-quality Sennheiser

"Our iconic MOMENTUM headphone family continues to set new standards through their fusion of superior sound quality and premium aesthetics"

Sebastian Rodens, Product Manager Audiophile at Sennheiser



sound without the wires. What's more, its Bluetooth headsets have fantastic battery life, so will give you hours and hours of listening pleasure – and with no cables, they also make great travelling companions.

The MOMENTUM Free is the latest addition to the range. An extremely compact and lightweight in-ear headphone, it packs all the style and substance you could want – just in a highly portable design. Immaculate sound is delivered straight to your ears using simple one-touch Bluetooth 4.2 and Qualcomm® apt-X™ support. Together they ensure crystal clear wireless transmission in true hi-fi sound. And thanks to a six-hour battery life and a high-quality ergonomic design, the headphones can be used for long periods, making them the perfect companion for today's on-the-go lifestyle – when not in use, the magnetic earpieces link together. The MOMENTUM Free also features the integrated VoiceMax microphone to ensure phone conversation clarity.

Whether you're on a plane, a train or a noisy street, Sennheiser and Bluetooth technology will make travelling a more enjoyable experience. And whatever your style, you can be sure Sennheiser has a brilliant, cutting-edge solution to suit you.

SENNHEISER

TO FIND OUT MORE

visit *sennheiser.com*

SHAPING THE FUTURE OF AUDIO

PXC 550

This sleek wireless headset allows users to make calls and change tracks directly from the ear cup-mounted controls. With up to 30 hours' battery life, they make the perfect travel companion.

HD 4 SERIES

The first Bluetooth models in Sennheiser's HD 4 range, the HD 4.50BTNC and HD 4.40BT can also be paired with the manufacturer's free sound-tuning CapTune app.

MOMENTUM FREE

The most compact Bluetooth headphone in the range, it delivers immaculate wireless hi-fi sound, six-hour battery life and a comfortable all day listening experience thanks to its ergonomic design.

Astell&Kern

A&ultima SP1000

INTRODUCING A TRULY LUXURY LISTEN

Introducing the Astell&Kern A&ultima SP1000, a new flagship player that changes what is possible from portable audio, in terms of both performance and desirability. The SP1000 takes the award-winning success of the AK380, launched two years ago, and raises the quality bar for high-resolution sound on the move.

Available now in **Stainless Steel** and **Copper** editions

- 32bit 384kHz Bit to Bit Playback
- NATIVE DSD 11.2MHz
- DAC DAC AK4497EQ Dual DAC
- Octa-core CPU
- -0.01 0.0 0.01 Parametric EQ
- 200fs VCXO Reference Clock
- USB 3.0 (Type-C)
- Fast Charging
- 5" 720 x 1280 Touch Display
- Stainless Steel / Copper Body
- Multi Function Wheel Key
- Max. 512GB

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CLARITY CONTROL

KEF has been making music sound better for more than 50 years... and now it's re-invented the wireless speaker

When former BBC electrical engineer Raymond Cooke founded KEF in 1961, The Beatles had yet to release their first single. While the Fab Four would go on to change the course of music history in the years that followed, Cooke's own musical revolution was already underway in a small Nissen hut in Kent. Under his pioneering inventiveness, KEF successfully brought professional studio sound into the audiophile's home for the first time with the release of the legendary LS3/5A loudspeaker in 1975 – the result of KEF's collaboration with the BBC.

More than four decades later and still headquartered in Maidstone, KEF continues to lead the way in audio innovation, stepping up to the challenges of the digital age with the LS50 Wireless – a cable-free, high-resolution music system that brings rich, multi-dimensional sound to a new generation of digital music lifestyles.

KEF's signature Uni-Q technology, now in its 11th generation, places the tweeter in the acoustic centre of the bass/mid-range cone, dispersing HF sound more evenly throughout the room. It's a feature that cannot be reproduced by any other active speaker. Crossover timing correction means every note, both high and low frequency, hits your ears at the same time, delivering three-dimensional sound and full enjoyment from your music no matter where you sit in the room.

A dedicated smartphone app with Tidal integration can remotely adjust how the LS50 Wireless sounds using selectable EQ sliders to compensate for different mounting scenarios, placement and positioning. Sound optimisation is also available through a touch-sensitive control panel on the master speaker, while comprehensive connectivity options allow users to connect up to 12 devices, including computers, smartphones and tablets for high-resolution streaming over Wi-Fi and Bluetooth.

Plug and play options like analogue and optical connections offer an incredible TV listening experience, and bring vinyl back to life. It means listening to music in exactly the way artists intended them to be heard when they were first recorded, and explains why the LS50 Wireless won the 2017/18 European Imaging and Sound Association award for best wireless loudspeaker.

Available in three sharp colours: titanium grey/red; gloss black/blue and gloss white/copper, the right colour combination to match your home is easy to find.

TO FIND OUT MORE
visit *uk.kef.com/ls50-wireless*
info.uk@kef.com

KEF

TOTAL CONTROL

Razer's new headsets are built to give gamers the ultimate gift: an unfair advantage on the battlefield

mmersion, precision and control. These are the principles driving the design of Razer's Kraken 7.1 V2, a new surround sound gaming headset that's more intelligent, customisable and powerful than ever before. So whether you like to lay down sniper fire in /Battlefield/, ambush your enemies in /Battlegrounds/ or dodge bullets in /Destiny 2/, Razer is here to help you hear your opponents before they hear you.

Let's start with Immersion: it's a delicate thing. Next-Gen games are built to draw us in to worlds so convincing that we want to dive in, head first, but if what you see and what you hear don't match up, the illusion can quickly fade. That's why Razer created Synapse, a software engine that harnesses the power of the Kraken headset to optimise your audio to your preferences. Everyone's hearing is different. Headphones and headsets typically ignore this fact, but Synapse tunes up your audio via a series of tests. To understand your hearing, Synapse plays you a sound effect and you tell the software which direction you think the audio came from. Then a set of algorithms, built on the knowledge of how ear size and shape affects the way you hear, calibrates the best audio for you. This way you can experience a game as it was designed to be played. Alternatively you can simply create your own perfect, personal sound setup, so you can hear your favourite games the way you want. You can play them anywhere you like too: Synapse saves your preferences to the cloud letting you access your custom settings wherever you are.

Of course, Immersion is great, but what Razer's really offering is a headset that gives

Of course, Immersion is great, but what Razer's really offering is a headset that gives its users a competitive edge

TECH SPECS

Drivers: 50 mm, with Neodymium magnets

Connection type: Analog 3.5 mm

Ultra-durable Kevlar™ reinforced cable

Oval ear cushions: Designed for full-ear coverage, perfect for long-wearing comfort

Microphone quick mute toggle

Frequency response: 12 Hz – 28 kHz

Impedance: 32 Ω @ 1 kHz

Sensitivity (@1 kHz): 123 dB

Input power: 30mW (Max)

its users a competitive edge. The precision and control offered by the Kraken's 7.1 virtual sound stage combined with Synapse, means you you can pinpoint footsteps better than your opponent. To the uninitiated gamer this might sound petty, but anyone who's jumped into a online multiplayer game, from *Overwatch*, to *Counter Strike* to *PlayerUnknown's Battlegrounds*, understands that situational awareness is often the difference between winning and losing. Finally, the Kraken's also been fitted with new drivers, larger than its predecessor's – to create a bigger, bolder, bassier soundscape. Obviously this provides plenty of "shock and awe", but it also ensures that you'll hear your team mates with total clarity.

Razer's headsets have been used in the noisiest, loudest professional gaming arenas, so naturally Razer has equipped them with digital microphones that offer sound-cancelling tech. This means that whether you're sat in a bustling internet cafe or a busy living room, your voice is the only thing your teammates will hear. The Kraken 7.1 V2 is also built to roll with the punches of online gaming: the aluminium body is light and durable and the microphone is fully retractable, protecting it when you travel. Razer has also spread the weight of the headset out evenly across its frame, to make sure lengthy sessions are comfortable and distraction-free. Ear cushions are larger, softer and better at isolating you from the room, with special channels molded into the foam to accommodate anyone wearing glasses.

Release your gaming potential, unleash the Kraken 7.1 V2.

RAZER

TO FIND OUT MORE
visit *razerzone.com*

Mission LX2

Simply Excellent Speakers

LX Series speakers are smart, practical and affordable, sporting a sharp, classic but modern look in keeping with Mission's customary design focus. Above all, they communicate music with engaging energy and detail, bringing performances to life with all the vibrancy and finesse one expects of Mission speakers.

While high performance mid/bass and treble units are the foundation of a great sounding speaker, if the cabinet is not properly reinforced it can be an unruly source of unwanted noise. To prevent this, extensive research and development was carried out by the designers of Mission to ensure internal cabinet robustness, eliminating any unwanted cabinet resonances and vibrations. Using a combination of CAD analysis, a lot of experimentation and extensive listening tests, the cabinet within each speaker has been braced at key points which means that the full frequency range is clear and detailed.

WHAT HI-FI? AWARDS 2016
Stereo speakers
Best standmount speaker under £300
Mission LX-2

"The Mission LX-2s get right to the heart of the music, almost as if they have a direct line to the studio"

avforums HIGHLY RECOMMENDED AWARD

"probably the best sub £200 stereo speaker that money can buy."

Hi-Fi Choice GROUPTEST WINNER

"A seriously talented standmount loudspeaker and a stone-cold bargain at the price"

Available from amazon · HOME AV direct

mission.co.uk

THE SOUND OF SUCCESS

*Digital sound quality has come along leaps and bounds in recent years, and multi-award-winning audio expert **Chord Electronics** is leading the charge*

As digital audio blossoms, the sound quality from audio devices has made significant progress in line with the better-than-CD-quality music offered by streaming and download services. British expertise is at the forefront of this new audio revolution, with the innovative, multi-award-winning audio expert Chord Electronics heading the way.

Despite coming up against the Asian consumer technology giants, Kent-based Chord Electronics is a world-leader in digital – internationally renowned for its proprietary technology. Uniquely, the company codes its own silicon chips rather than buying them off the shelf. This programming science has enabled music lovers to enjoy studio-grade sound quality from everyday devices, such as smartphones, when connected to Chord DACs (digital to analogue convertors). The company's range includes home hi-fi, but also portable and even pocket-size devices for travelling and commuting.

The company's new transportable Hugo 2 is, perhaps, the greatest distillation of Chord's proprietary tech. British designed and manufactured, Hugo 2 is a headphone amplifier and DAC that connects smartphones, tablets, PCs/Macs, gaming consoles and virtually anything with a digital output, to headphones and existing home audio systems – instantly upgrading both.

Chord's unique hardware and custom software processes audio with PC-like power, delivering higher resolution even from basic digital files such as MP3s. Connection is via Micro USB, plus there's Bluetooth and two further digital inputs for additional devices. The two headphone sockets allow for music sharing, and a standard RCA connection offers common connectivity to household audio systems. Hugo 2's built-in rechargeable battery gives seven hours' playback for travelling and commuting, which is enough for all but the longest journeys.

From music stored on phones and computers, to legacy CD collections, cherished tracks and favourite albums can now be delivered with sound quality quite unthinkable only a few years ago.

TO FIND OUT MORE
chordelectronics.co.uk/product/hugo-2

CHORD
Chord Electronics Ltd.

LISTEN UP...

*The award-winning speaker specialists at **Monitor Audio** have sought inspiration from the aerospace industry for their new Silver series*

British manufacturer Monitor Audio has been taking loudspeaker development to new heights for over 40 years – and now it's succeeded in doing that almost literally. The sixth generation of the firm's award-winning Silver series of speakers, released in July, incorporates material pioneered by the aerospace industry.

Ceramic-Coated Aluminium Magnesium (C-CAM), typically used in jet engine blades, has been used to create metal alloy driver cones and mid-bass drivers to deliver cutting-edge home theatre sound. Whilst extremely rigid, they are still light enough to deliver beautifully-detailed musical atmospherics and deep bass for movie action scenes without distortion.

Conventional cones made out of paper and plastic can easily bend or flex. In contrast, Monitor Audio's innovative C-CAM drivers are capable of operating to beyond the limit of human audibility without any sound coloration. The nine-model Silver series includes the ultra-compact Silver 50 bookshelf speaker, the super-slim Silver 200 floorstander, and the Silver 500 – perfect for audiophiles seeking high-performance and studio-quality sound in the home.

Made by the world's foremost experts in developing metal dome drivers, each model (apart from the subwoofers) features a re-designed 25mm Gold Dome tweeter for precise treble. The Silver series has an ultra-contemporary slimline build, with Monitor Audio enlisting the help of the National Physical Laboratory to make it. The NPL used a precision laser scanner to identify cabinet resonances and position internal bracings that minimise unwanted vibrations and sound interferences.

The innovative C-CAM drivers are much smaller than traditional designs, making for ultra-contemporary, more elegant cabinets with HiVe II ports positioned at the back. Each model is available in a variety of finishes: a new satin white, high gloss black, and real wood veneers in black oak, natural oak, rosenut and walnut.

MONITOR AUDIO

TO FIND OUT MORE
visit *monitoraudio.com*

SILVER 6G CABINET BRACING

Monitor Audio has several test methods and modelling techniques to ensure cabinet brace positioning is as efficient as possible – this includes using detailed computer models (as above).

The result is effective transparent speakers that impart as little colouration on the original recording as possible, such as the new Silver Series 100 (above).

iSINE

AUDEZE™

THE WORLD'S FINEST IN-EAR HEADPHONE

3.5MM COMPATIBLE

Made for iPod iPhone iPad

- World's first full-range planar magnetic in-ear headphones.
- Featuring Fluxor™ Magnets, 30mm planar magnetic diaphragms and patented Uniforce™ Voice-Coil technology.
- Delivering precise control and fast response times without distortion.
- Available with standard 3.5mm connection or also with Audeze's acclaimed Apple Lightning CIPHER cable. Ideal for the new iPhone 8 & iPhone X.
- Start with the iSine 10, or step up to the iSine 20, with an even longer Uniforce voice-coil for enhanced bass, clarity and imaging.

iSINE10

"A seriously impressive in-ear that sounds exceptional, particularly for users of Apple devices" - Hi-Fi Choice

Hi-Fi Choice RECOMMENDED

iSINE20

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audioengine

BEAUTIFULLY VERSATILE

From TV to turntable to Tidal whatever you enjoy listening to, **Audioengine HD6** speakers are here to make it sound better, in style

- Powered stereo speakers ready for all your audio sources
- Built-in amplification – streamline your system
- Analogue and digital connections
- Wireless Bluetooth music streaming
- Choose walnut and cherry real-wood veneers, or satin black
- Removable magnetic speaker grilles
- Sleek metal remote control
- Award-winning Audioengine quality

Available now at AUDIOVISUAL ONLINE

HELEN CZERSKI ON... RAINBOWS IN ICE

"HE FISHED OUT AN AXE, HACKED INTO A GLACIAL PIMPLE, AND OUT CAME ICE FILLED WITH RAINBOWS"

We love it when a gift that we've carefully chosen makes someone happy. But when the recipient of the present is a small child we have to accept that the real source of joy is often the packaging rather than its contents. Physicists have a similar streak, and can often be left in a corner happily playing with something that isn't meant to be the main attraction. This time, the culprit was one particular chunk of ice, on a day that had been filled with the stuff.

The star of the show was a cave in the side of a glacier, and we had spent an afternoon working there, filming for a BBC documentary. But right at the end of a long day, when everyone was tired and ready to go home, our guide said a child had once told him there were rainbows in the ice at one specific spot next to the cave. He fished out an ice axe, hacked into an unassuming glacial pimple, and out came a chunk of ice filled with rainbows. Except that wasn't quite it – there were sheets of blues, pinks and greens, glinting inside the clear ice. And once I had been given this toy to play with, I didn't want to leave.

As the colours in the ice were the same as those seen on soap bubbles, they were a dead giveaway of what was going on. Light hitting a thin soap film can reflect off both the near and far surfaces, and when those two reflections overlap with each other, some colours of the rainbow are enhanced and some suppressed. In any one spot, we just see one colour, the one that comes from the specific mix of the rainbow that's on offer from that place. And only some combinations are possible, which is why blue, pink and green dominate. But there was no soap in the ice to cause the effect. Instead, there must have been incredibly thin, sheet-like cracks, and light was reflecting off the near and far surfaces of the cracks. The blue colours told me that some of these cracks were only a few hundred nanometres thick, and as they widened, the colours merged into yellow, then pink, and then green. The colours let me see the width directly.

But ice cracks all the time. When you put an ice cube into a drink, you quite often hear the popping sound as cracks form. In this case, it's because the outer ice expands slightly as it warms (before it melts) and the mismatch in size between inside and outside forces the structure to break. So why do we never see colours in an ice cube? I suspect that it's because the cracks in an ice cube are too wide – they just open up until the inside and outside of the ice cube are the same size. My guess is that the cracks in this glacial ice followed hidden layers of stress, possibly left over from the ice flowing sideways under pressure. Instead of pulling apart, the two surfaces were just shunted over each other, leaving a truly tiny gap in between. The final sideways shimmy might even have been caused by the impact of the guide's ice axe.

As I held the ice, I could see the colours fading as the warmth of the sunlight softened the ice and the cracks vanished. The guide commented that this was the most excited he had seen me all day. I could have spent hours there, looking at the prettiest fracture patterns I had ever seen. But everyone else was hungry and waiting for me, so eventually I had to leave. Still, I carried my excitement home with me, because the unexpected colours in the ice had been the best toy of the day.

Dr Helen Czerski is a physicist and BBC presenter. Her new documentary on temperature will be shown in late 2017.

NEXT ISSUE: WHY IT'S EASIER TO HEAR PEOPLE DOWNWIND

ILLUSTRATION: KYLE SMART

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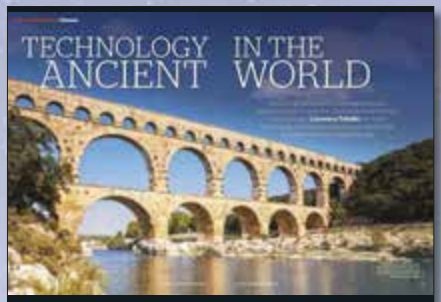
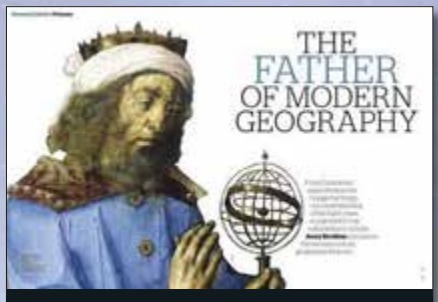


Global milestones in technology



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Q&A


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Astronomer, astrophysicist


ALEX FRANKLIN-CHEUNG
Environment/ climate expert


DR PETER J BENTLEY
Computer scientist, author


PROF ALICE GREGORY
Psychologist, sleep expert


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LUIS VILLAZON
Science/tech writer


DR AARATHI PRASAD
Biologist, geneticist


PROF ROBERT MATTHEWS
Physicist, science writer

YOUR QUESTIONS ANSWERED

NOVEMBER 2017 | EDITED BY EMMA BAYLEY

PHOTO: GETTY

Some populations of monarch butterflies will migrate south nearly 5,000km to overwinter in Mexico and California

How do butterflies manage to fly in the wind?

BRIAN MCHALE, LONDON

Scientists have studied this by tethering individual insects in wind tunnels and training them to fly towards flowers, while filming them in slow motion. They have found that the lightweight insects use a range of flying styles to combat the challenges of staying airborne on windy days. They might clap their wings behind their backs to push themselves forward or 'waggle' by twisting their flapping wings, therefore creating miniature whirlwinds that roll off the wing and lift it up. Good posture is important, as is warming up the flight muscles before flight.

But windy days can be useful. With help of tailwinds, migrating butterflies can travel at 100km/h at an altitude of several hundred metres! cc

Why does eating spinach make my teeth feel weird?

EDWARD SEYMOUR, HOVE

As well as being a great source of iron, spinach is packed full of oxalic acid. When you chew spinach, calcium in your saliva reacts with the oxalic acid to create insoluble calcium oxalate crystals. These stick to your teeth and make them feel gritty or chalky. You may feel that drinking milk might help but its high calcium content will only make things worse. The good news is that spinach does not damage your teeth. In fact, calcium oxalate crystals are used in some dental treatments claiming to eliminate sensitivity by targeting dentine, which lies below the enamel. **ED**

Why do some people love horror films?

WILLIAM BENNETT, PETERBOROUGH

Evolutionary psychologists say that horror films tap into our primal fears, such as fear of contamination and fear of being eaten, which explains the popularity of zombie movies and films featuring oversized carnivores. Horror films essentially provide a safe way for us to rehearse mentally how we would cope with age-old dangers. Curiously, the more negative emotions a person says they experience during a horror flick, the more likely they are to say they enjoy the genre. One theory is that this is because some people, especially sensation-seekers, find pleasure in the feelings of relief that follow after intense fear. CJ

Does Stockholm Syndrome exist?

MARY LENNARD, DONCASTER

Reports earlier this year that some of the girls kidnapped by Islamist militants in Nigeria wanted to stay with their captors led to claims they were experiencing Stockholm Syndrome. This was a reference to a phenomenon first noted following a failed bank robbery in Stockholm in August 1973. Police negotiators found that the hostages had formed a positive bond with their captors. This led to claims that their fear and loss of control had led to even small acts of kindness triggering irrational levels of gratitude. However, following her release, one of the hostages insisted their response was a rational way of responding to the situation, increasing their survival chances. Considerable doubt still surrounds the existence of Stockholm Syndrome, and it is not recognised by official psychiatric diagnostic handbooks. **RM**

Why do leaves change colour in autumn?

DAVINA TAUNTON, LEDBURY

Deciduous trees drop their leaves to reduce water loss during winter, when it is too cold to grow. But rather than just discard the entire leaf, the tree recycles as much of it as possible, to conserve nitrogen. The green chlorophyll is the first to be broken down and reabsorbed, which allows yellow carotenoids and red anthocyanin to show through. **LV**

IN NUMBERS

24

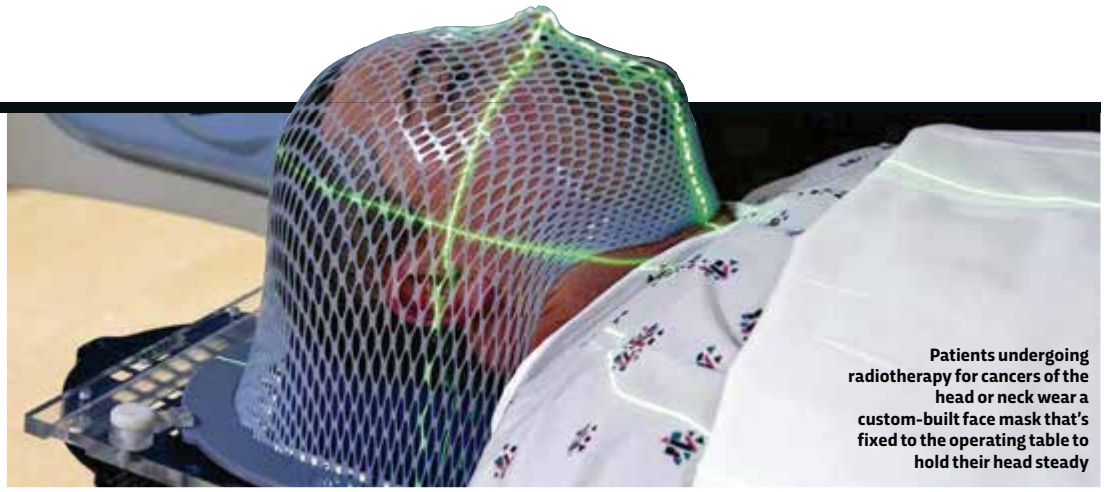
The percentage of girls in the UK who are showing signs of depression at the age of 14, according to a study by the University of Liverpool.

250

The length, in metres, of a fatberg found in a London sewer in September – that's longer than Tower Bridge!

0.5

The time, in milliseconds, it takes predatory *Myrmoteras* ants to snap their jaws shut.



Patients undergoing radiotherapy for cancers of the head or neck wear a custom-built face mask that's fixed to the operating table to hold their head steady

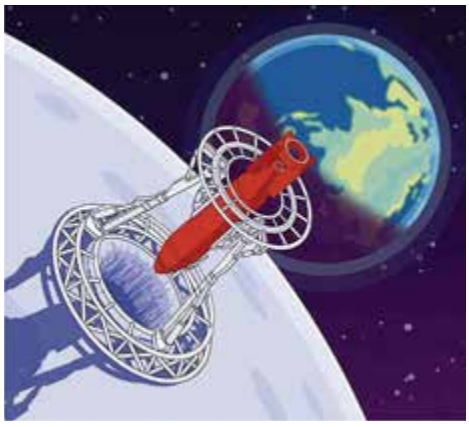
How does radiation kill cancer if it causes cancer?

ODYSSEUS RAY LOPEZ, US

It's rather like the way guns can be used to commit crime, or stop it. Radiation causes cancer because its high-energy photons can cause breaks in the DNA strands in your cells. Cells can repair this damage up to a point, but sometimes the repair isn't perfect and leaves some genes defective. If the break affects one of the many tumour-suppressing genes in your DNA, that cell can become cancerous. But cancer cells are also more vulnerable to radiation than ordinary cells. Part of what makes them cancer cells is their ability to divide rapidly and this normally means that some of the DNA 'spellcheck' mechanisms are turned off. So when a cancer cell suffers a break in a DNA strand, it's less likely to repair it correctly. Depending where the break occurs, it might either kill the cell outright, or make it reproduce more slowly. Radiation therapy uses a focused beam that is aimed at just the part of the body with the tumour, and the dose is carefully calculated to cause the minimum collateral damage to healthy cells. Even so, radiation therapy does very slightly increase your chances of developing a second cancer. **LV**

THE THOUGHT EXPERIMENT

WHAT WOULD HAPPEN IF WE BLEW UP THE MOON?



1. EXPLOSION

The gravitational binding energy of the Moon is 120 million, trillion gigajoules. This means that unless you deliver that much energy in one go, the Moon will just crack apart and reform into a sphere. To blow it up, you'll need to drill mine shafts hundreds of kilometres deep, all over the Moon, and drop a total of 600 billion of the largest nuclear bombs ever built down them.

2. DEBRIS

Any Moon debris that falls on Earth will only have about 1 per cent of the impact energy of a similar-sized asteroid, because of the lower orbital speed. But smaller stones would still be lethal as they would be so numerous. The kinetic energy of the stones would be absorbed by the atmosphere as they burned up, heating the atmosphere until all life was incinerated.

3. TILT

The remaining debris will spread out into rings around the planet. Without the stabilising tidal drag from a single moon, the Earth's axial tilt will wobble far more than it does now. Over tens of thousands of years, Earth could tilt all the way past 45°, so that most of one hemisphere faces the Sun continuously, and the other is in perpetual darkness.

PHOTOS: GETTY X3, SHUTTERSTOCK ILLUSTRATIONS: RAJA LOCKEY

Q&A

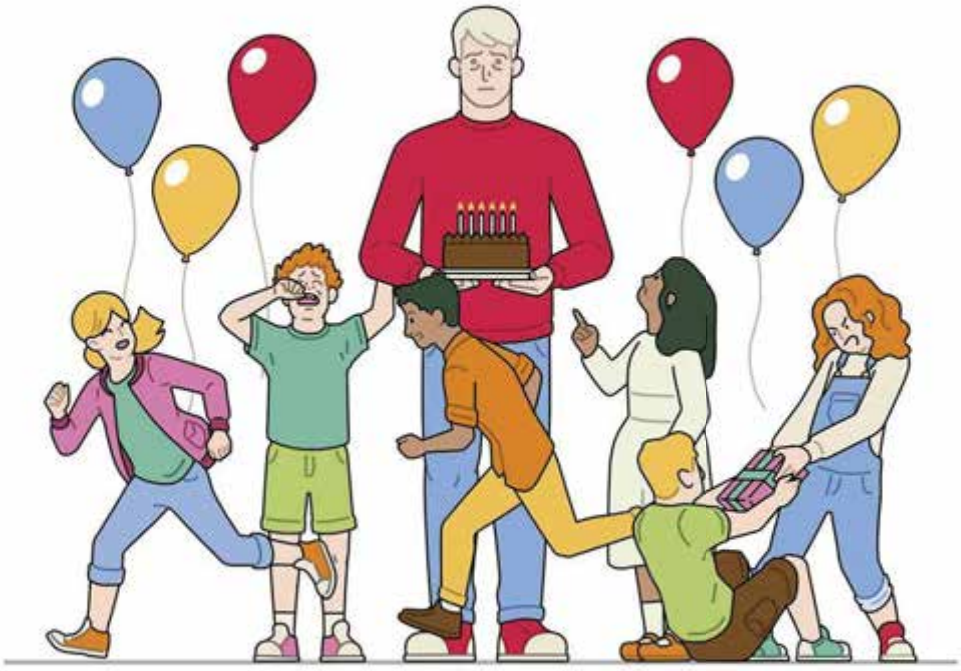
What was Stonehenge made for?

AMILIE KENDAL, AGE 10, PRESTWICH

We can't know for sure because the people who built it didn't leave any written records. But Stonehenge isn't one thing. It is a sacred site that has been continually added to and rearranged for over 5,000 years. The earliest construction in 2900 BC was a circular bank and ditch, with an inner ring of large timber posts. Three hundred years later, a ring of standing stones was added, using stones dragged from Wales, 240km away. Then a hundred years later, the 'trilithons' (standing stones with lintels) were added. Even after that, there is evidence that the arrangement of the stones changed several more times. Like the O2 arena, or Trafalgar Square, Stonehenge was probably used for several purposes at the same time. It was a festival venue, temple, burial ground and astronomical calendar. **LV**

FACT OR FICTION?

SUGAR MAKES CHILDREN HYPERACTIVE



FICTION

In 1978 a study of 265 hyperactive children found that they all had abnormally low blood sugar levels. This might have been a sign that they had previously eaten too much sugar and were now 'crashing'. But almost every study since then has failed to find any link. A meta-analysis in 1995 looked at 23 studies and found that there was no statistically significant effect of sugar on any of 14 different measures of behaviour. Parents who see hyperactive children at birthday parties may blame the cake and sweets, when it is really just the excitement of the party itself. In fact parents who are told their child has been given a sugary drink are more likely to judge their behaviour as hyperactive, even if it was really a sugar-free drink that had been drunk. **LV**

How do QR codes differ from barcodes?

HELENA COOPER, SALISBURY

Barcodes come in all shapes and sizes. The first successful barcode was the Universal Product Code (UPC), used for tracking products in stores, which encodes 12 numbers. Other barcodes hold more information, for example the Royal Mail Mailmark (TM) type L barcode – which encodes 26 characters including ID, postcode and delivery point. QR codes are another kind of barcode, and there are many sizes. A version 4 QR code is 33 x 33 pixels in size and encodes up to 50 characters. A version 40 QR code is 177 x 177 and stores 2,953 bytes, or up to 7,089 digits. This particular QR code is so densely packed it looks like a picture of a snowstorm, and is rarely used because it's difficult to scan successfully. **PB**

PHOTOS: SHUTTERSTOCK(2) • NATIONAL GEOGRAPHIC ATLAS OF ILLUSTRATIONS: RAJA LOCKEY

This tunnel in a shopping mall in Nanjing, China contains over 400 QR codes for products and games. In China, QR codes are incredibly popular – shops and street vendors allow customers to scan a QR code to pay for goods. Even buskers and beggars offer QR codes!

Could icebergs be towed to solve water shortages?

R STATHER, BROMSGROVE

First mooted almost 60 years ago, this 'crazy' idea may finally be tried next year. A company in Abu Dhabi has unveiled plans to tow two icebergs from Antarctica to the Emirates. Ironically, the biggest challenge lies in the reluctance of ice to melt. Turning a big berg into fresh water at a reasonable rate requires the power output of a large power station. **RM**

Are chin dimples hereditary?

PETE GARIBALDI, KETTERING

A chin dimple, or cleft chin, can be hereditary, and passed down in what is known as a dominant trait. Our parents each give us one version of the gene involved in this trait. The two versions are not equal: 'dominant' means that the inheritance of just one copy of the cleft version will give you a chin cleft of some description. It is less likely, but not impossible, to inherit no cleft versions of the gene and still have a cleft chin. What you pass on to each of your children will be another shuffle of the versions, so that, in turn, they may or may not show the cleft. **AP**

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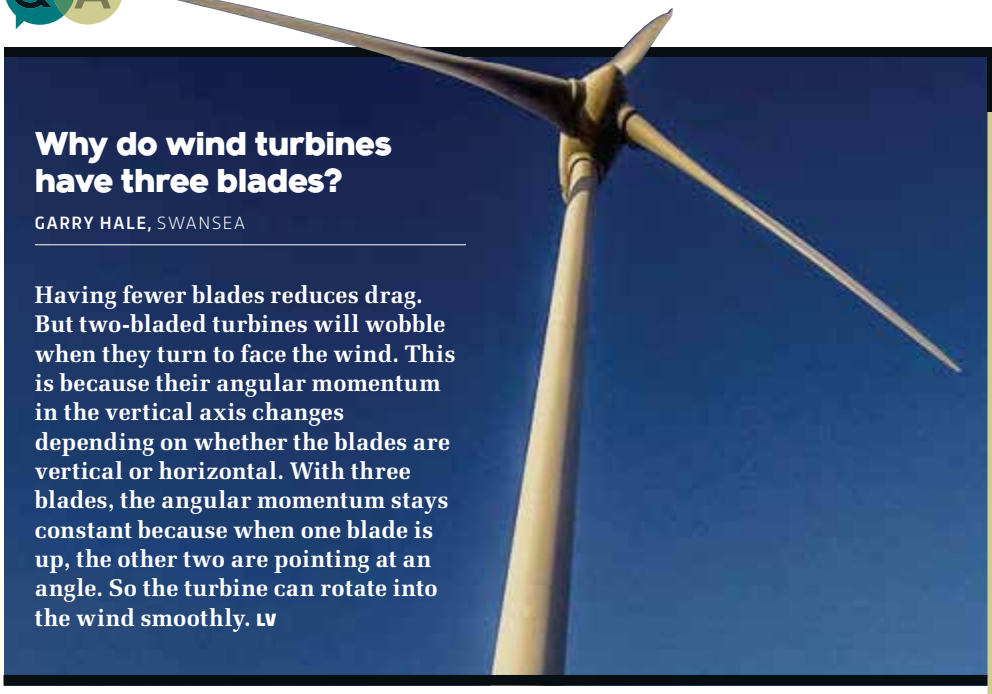


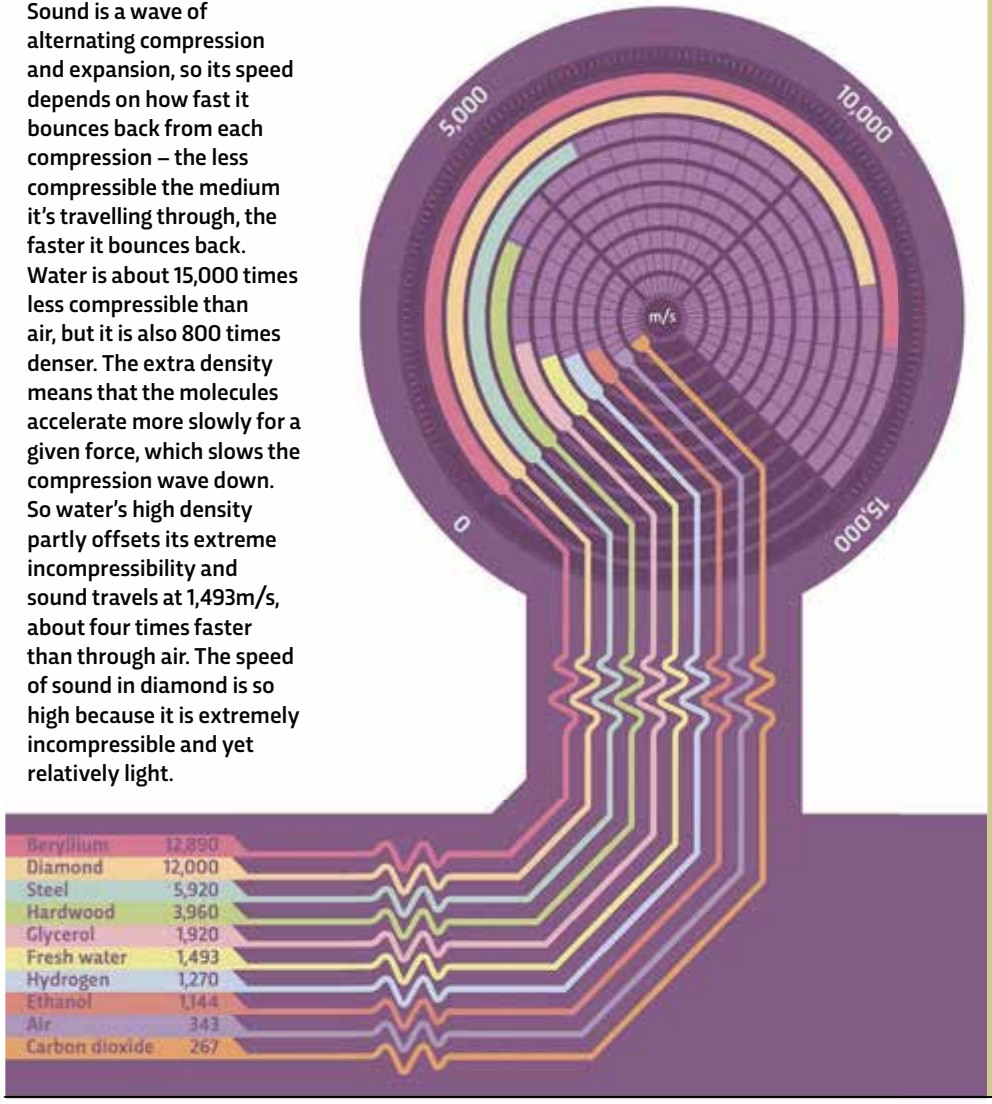
Why do wind turbines have three blades?

GARRY HALE, SWANSEA

Having fewer blades reduces drag. But two-bladed turbines will wobble when they turn to face the wind. This is because their angular momentum in the vertical axis changes depending on whether the blades are vertical or horizontal. With three blades, the angular momentum stays constant because when one blade is up, the other two are pointing at an angle. So the turbine can rotate into the wind smoothly. LV

HOW FAST DOES SOUND TRAVEL THROUGH WATER?

Sound is a wave of alternating compression and expansion, so its speed depends on how fast it bounces back from each compression – the less compressible the medium it's travelling through, the faster it bounces back. Water is about 15,000 times less compressible than air, but it is also 800 times denser. The extra density means that the molecules accelerate more slowly for a given force, which slows the compression wave down. So water's high density partly offsets its extreme incompressibility and sound travels at 1,493m/s, about four times faster than through air. The speed of sound in diamond is so high because it is extremely incompressible and yet relatively light.



WHAT CONNECTS...

PRINCESS LEIA AND THE MEXICAN REVOLUTION?

1.

Princess Leia was brought up in a noble household in a galaxy far, far away. But she dedicated herself to the downfall of the established regime, by force if necessary.

2.

To most of us she is most famous for her iconic hair style. The twin 'cinnamon bun' look is handy for keeping your ears warm on chilly planets like Hoth.

3.

In 1977, George Lucas was on the hunt for a distinctive look for Leia. He was inspired by Mexican fashions in the early 20th Century, but women there mostly wore their hair long.

4.

Except for Clara de la Rocha. She was a revolutionary hero and guerilla fighter who became a colonel during the 1910 Mexican Revolution and fought in several battles.

PHOTO: GETTY X2, SHUTTERSTOCK X2, REX, LUCAS MUSEUM OF NARRATIVE ART ILLUSTRATION: RAJA LOCKEY

WHAT IS THIS?

Salt harvesting
In Vietnam's Bạc Liêu Province, workers harvest salt in the scorching sunshine. To get the salt, seawater is diverted at into shallow pools. As the water evaporates, the salt is left behind. The workers gather the salt into piles using a tool called a cào, before sending it away for storage. They have to work fast – according to residents, a downpour of rain will dissolve all the salt.

...WHEN I EXERCISE?

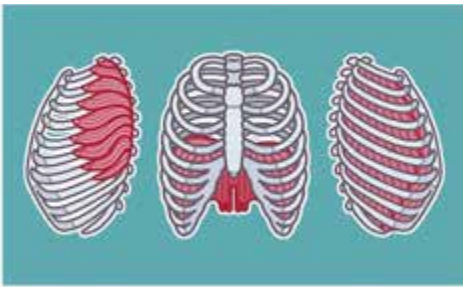
Exercise diverts blood from your liver and digestive system to your skeletal muscles. Hormones tell the body to convert fat into glucose, reduce the pain you feel and improve your mood. Muscles generate lactic acid as a by-product of intensive exercise and, as this builds up, the pH of the blood around the muscles drops. This drop in pH eventually prevents the muscles contracting further. At this point, you need to rest to allow the lactic acid to be metabolised.

1. Brain

The brain makes neurotransmitters, like serotonin, dopamine and GABA. This is part of the reason why the brain consumes more energy during exercise.

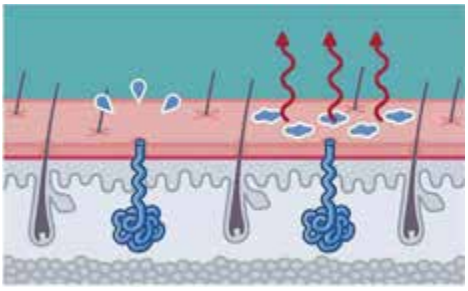
2. Heart

Adrenaline levels rise, which stimulates the heart to beat faster. Capillaries in the muscles open wider, increasing blood flow there by up to 20 times.



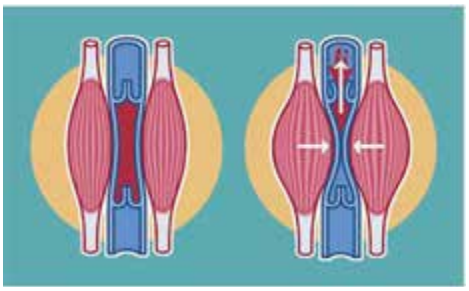
3. Lungs

The muscles of the ribcage assist the diaphragm to pull in up to 15 times more oxygen than at rest. Breathing gets faster but also deeper.



4. Skin

Your two million sweat glands can produce 1.4 litres of sweat per hour. Waste heat is carried away by the latent heat of evaporation as it dries.



5. Muscles

As you exercise, the large muscles in your arms and legs squeeze the veins running through them, pumping blood back to your heart.

6. Bones

High-impact and weightlifting exercises stimulate bone formation and reduce the rate of calcium loss as we get older.

How much does Earth's atmosphere weigh?

RICHARD EVANS, ASHFORD

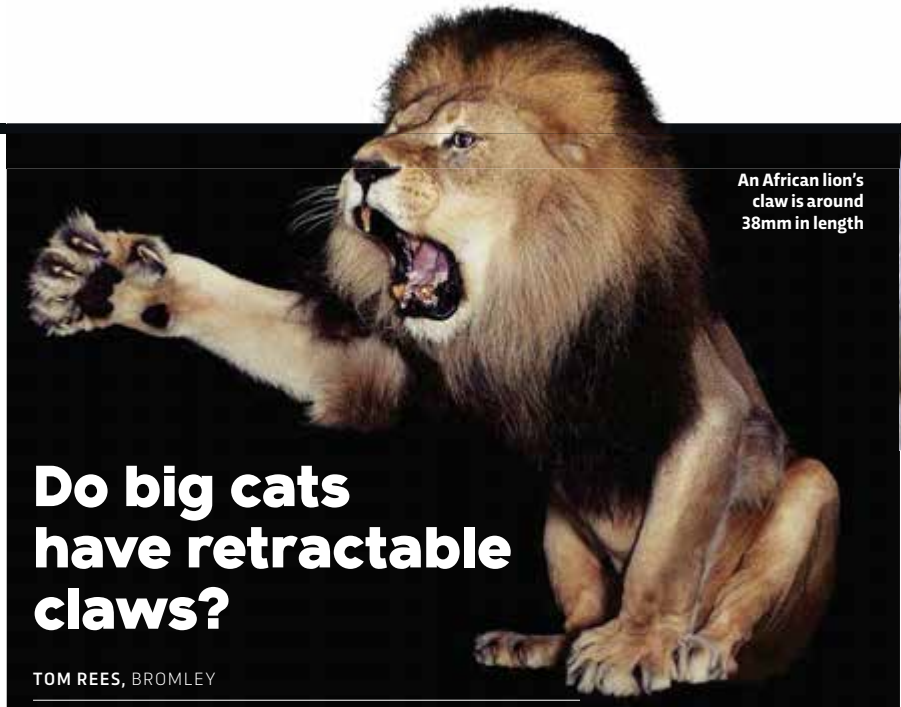
Just over five quadrillion tonnes. Air is surprisingly heavy. A cubic metre of air at sea level weighs about 1.3kg and all the oceans only weigh 270 times as much as the atmosphere. We tend to underestimate the mass of air because we spend all our lives surrounded by it, and it presses down on us from all directions equally. LV

Why do gums recede?

LEWIS POLLARD, LEEDS

The main cause is gum disease. A 2010 study found that 47 per cent of Americans over 30 had some degree of gum disease. The bacteria attack the bone tissue in your jaw just behind the gum and cause it to slowly erode. Without healthy bone tissue to act as a scaffold, the gums first peel away from the tooth and eventually shrink back. Regular toothbrushing and flossing can fight gum infection but overbrushing damages gums too. LV

PHOTOS: GETTY X4, REUTERS ILLUSTRATIONS: RAJA LOCKEY



An African lion's claw is around 38mm in length

Do big cats have retractable claws?

TOM REES, BROMLEY

It depends how we define the group of cats referred to as 'big cats'. Technically, these are the roaring cats, like tigers, lions, jaguars and leopards, and they all possess fully retractable claws like domestic cats. This adaptation ensures their claws are protected by a sheath of skin when they are not being used to catch prey, climb, scratch or provide traction. Cheetahs are sometimes referred to as 'big cats', but they have semi-retractable claws that look more dog-like than cat-like. As the fastest land mammals, reaching top speeds of 114km/h (71mph), they need extra traction while running, so their protruding claws act like sprinters' shoes. CC

This instrument is made from bear bone and is 45,000 years old

When did humans first make music?

MARGARET HUTT, AMERSHAM

The oldest discovered musical instruments in the world (flutes made of bones and mammoth ivory) are over 40,000 years old. But instruments and song may be far, far older. In his book *The Descent Of Man*, Charles Darwin wondered whether our language abilities had started with singing, and if that was the reason for our pleasure in music. By studying fossils, we can establish that once our ancestors had the horseshoe-shaped hyoid bone in the throat in a similar position to modern humans, they would have had the physical ability to sing as we can. That date is over 530,000 years ago. **AP**

QUESTION OF THE MONTH

Where do deleted computer files go?

LILLIAN GUAINIERE, RYE

Computer files are stored as lots of ones and zeros. An ordinary delete operation will either just move the file to a new area called 'Trash', or it may make the computer forget where the file is, without removing the file. Even reformatting a drive may not work because it's like removing the table of contents in a book – all the pages of words are really still there. You may need special software to permanently delete files. This software will overwrite those pesky ones and zeros, setting them all to zero or to random values. When you've done that to a file, it ceases to exist, and the data is gone forever. **PB**

WINNER!

Lillian Guainiere wins a pair of NOVA True Wireless Earbuds (£60 approx, **trndlabs.com**). These earbuds fit comfortably in your ear without the hassle of wires, while simple one-button control makes them perfect to use while exercising or travelling. Plus, their compact power case extends play time and charges up your devices to boot.

NEXT ISSUE:

Why does water improve whisky?

Why are lips red?

How do starfish regenerate limbs?

Email your questions to **questions@sciencefocus.com** or submit online at **sciencefocus.com/qanda**

OUT THERE

WHAT WE CAN'T WAIT TO DO THIS MONTH

NOVEMBER 2017 | EDITED BY JAMES LLOYD

ILLUSTRATION: ALASTAIR BONNETT/AURUM PRESS

01

NEW VIEWS: THE WORLD MAPPED LIKE NEVER BEFORE
BY ALASTAIR BONNETT, OUT 26 OCTOBER (£25, AURUM PRESS).

SEE THE WORLD ANEW

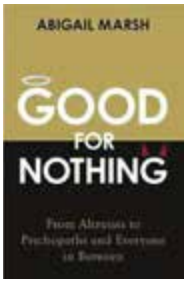
Incoming! Each of these dots is an asteroid strike, sized according to its energy of impact. Created using data from NASA's Near-Earth Object Observations Program covering 1994 to 2013, the asteroids range in size from 1 to 20m. Fortunately, they all break up when they hit Earth's atmosphere, arriving at the surface as far smaller meteorites. But these can still do some damage. See if you can spot the Chelyabinsk strike that exploded over southern Russia with a force equivalent to 500 kilotonnes of TNT in 2013 (clue: it's the largest orange dot on the map).

***New Views* brings together 50 maps showing everything from lightning strikes and ant populations to religious diversity and the world nut trade. Accompanied by insights from social geographer Alastair Bonnett, the maps are beautiful to look at, and a timely reminder that our global connections are stronger than the borders which separate us.**

02

LEND A HAND

GOOD FOR NOTHING BY ABIGAIL MARSH
OUT 19 OCTOBER (£14.99, ROBINSON).



Why would someone risk their life for a stranger? After experiencing an extraordinary act of kindness, psychologist ABIGAIL MARSH made it her mission to understand altruism. She talks to JAMES LLOYD

What was the act of kindness that you personally experienced?
When I was 19, I was driving home late at night on the biggest freeway in Washington State when a dog ran out in front of me. I swerved to avoid it, but ended up hitting it anyway, and my car was sent spinning. I found myself in the fast lane, facing backwards into oncoming traffic, and then the engine died. I was sure I was going to die. Cars and trucks were speeding towards me, swerving at the last minute. But then this guy suddenly appeared at the passenger window. "You look like you could use some help," he said. I let him get into the driver seat and he managed to get the car going again, launching us across the freeway and parking me behind his own car. After making sure I was okay, he just left – I didn't know anything about him.

I figured out later that he had parked on the opposite side of the freeway and run across five lanes of traffic in the middle of the night. I live to this day with the regret that I don't think I ever said thank you.

And this got you thinking about the concept of altruism?
Until a stranger has put their life on the line for you, you can't fully grasp the gravity of it. Why would someone do that? It doesn't make sense from a scientific perspective, either. There are lots of good evolutionary explanations for why showing altruism to those close to you can benefit them, and in turn benefit you. But why would someone sacrifice their own welfare for a stranger? That's a real puzzle.

How did you go about investigating this?
For about seven years I've been studying a group of people who've all done something extraordinary: donating one of their kidneys to a stranger. This is at no small cost to themselves. A donor will lose over $2,000 due to travel, missed work and other expenses. Then there's the recovery time – at least a couple of weeks – plus possible health complications later down the line, and even a small (less than one per cent) risk of death associated with the surgery itself. For most of the history of transplantation you weren't allowed to donate a kidney to a stranger, because these people were assumed to be insane.

Why are people willing to do it, then?
I've asked the donors to unpack that moment between when they first heard about the need for organs and when they decided to donate one. A lot of us have that same information but don't make the same decision. What I find really interesting is that the donors often have trouble understanding why someone *wouldn't* donate. Their decision is happening at an intuitive level – it's not a rational cost-benefit analysis.

What do you think makes someone a 'super altruist'?
We've carried out brain scans and behavioural tests with these altruists, and found that they're better at recognising other people's fearful facial expressions – they're more attuned to the suffering of others. They also show more activity in their amygdala – a region of the brain that's important for recognising fear. This makes sense, because when we see someone in distress we tend to have a spontaneous caring response, which in theory should give rise to altruistic behaviour.

These findings also tie in with what we know about people who are psychopathic, who have very little empathy and under-reactive amygdalas, and don't recognise when others are frightened.

Are most of us selfish by nature?
Very few of us are fundamentally selfish. There's a continuum of caring, from psychopaths to these altruists, and most of us are somewhere in the middle. The average person has a capacity for altruism towards strangers, but it's not as robust or as frequent as the people I've studied. We care the most for those dear to us, and then the caring response drops off as we move outside our closest circle.

We don't know exactly what makes someone an extraordinary altruist in the first place, but it's likely to be a mixture of genetic and environmental factors – there's no one thing, like a religion or family background, that links them all.

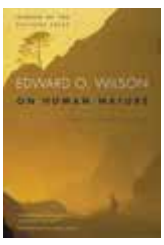
What can we learn from these people?
Just knowing these people exist gives you a different perspective on human nature. Helping strangers is becoming more common, and it's been shown that people who help others, especially when it's truly motivated by care, tend to be happier. Doing something altruistic is beneficial for everyone, even if it's something small.

PHOTO: GETTY

Rescuers and volunteers look for survivors in a textile factory that collapsed two days after the recent Mexican earthquake

AUTHOR'S BOOKSHELF

Three books that inspired Abigail Marsh while writing *Good For Nothing*



ON HUMAN NATURE
BY EDWARD O WILSON
(£24.95, HARVARD UNIVERSITY PRESS)

This lucid, seminal book explained human social behaviours, including aggression and love, in terms of basic principles of biology. It helped break down the barriers between the natural and social sciences, and paved the way for my discipline, social neuroscience.

MOTHERS AND OTHERS
BY SARAH BLAFFER HRDY
(£17.95, HARVARD UNIVERSITY PRESS)

A fascinating exploration of communal parenting around the world, this book persuasively dismantles the insane idea that human babies should be tended to by a single caregiver. In doing so, it showcases the many forms of care that permeate our societies.

MOTHER TONGUE
BY BILL BRYSON
(£9.99, PENGUIN)

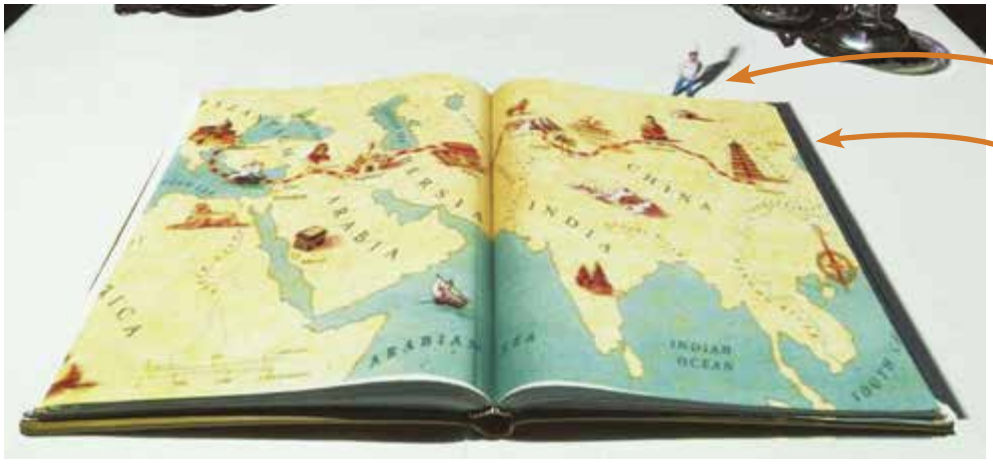
The first time I read this book about the English language I was nearly kicked out of a library for laughing too loudly. Bryson makes potentially obscure topics such as grammar and etymology vivid and accessible, which I hope is also the case for my discussions of fear, care and the brain.

03

MEET LE PETIT CHEF

There are plenty of top chefs in London, but not many who are 58mm tall. Arriving in October 2017, Le Petit Chef is a two-hour dining experience that combines nifty projection mapping technology with a six-course meal. The diminutive digital chef is brought to life in front of the diners' eyes, with animations telling the story of his search for culinary inspiration as he travels the globe in the footsteps of Marco Polo. At each of the chef's destinations, the diners are served a corresponding dish – think traditional Arabian, Indian and Chinese cuisine, plus a fish amuse-bouche in France and a sorbet in the Himalayas.

The world's smallest chef is about to hit the big time in London



HOW IT WORKS

A small projector positioned above the diners beams the image directly onto the table below.

The animation is custom-made for the entire surface, so physical props positioned in the right place, such as books and plates, become a canvas for the story of Le Petit Chef. Expect to see birds, boats and fire-breathing dragons.

The image is a flat projection, but clever use of perspective and length distortion creates the illusion of 3D.

The Belgian team behind the experience – Skullmapping – began by mapping projections onto buildings, but wanted to try their technology in a smaller, more intimate setting.

Between animations, while the diners eat, the projection becomes a patterned tablecloth. The food and background music is chosen to match Le Petit Chef's current location on his culinary travels.

For his grand finale, Le Petit Chef appears on the diner's plate and uses the ingredients he's collected throughout his journey to rustle up a dessert. And then, voilà, you're served the real thing. Bon appétit!

PHOTOS: SKULLMAPPING X3, BBC X2

04

BLUE PLANET II
BBC ONE, FROM LATE OCTOBER
CHECK **RADIOTIMES.COM** FOR DETAILS.

EXPLORE THE DEEP

Following on from the runaway success of *Planet Earth II*, *The Blue Planet* is the latest classic David Attenborough series to be given a modern-day makeover.

The new seven-part series, imaginatively titled *Blue Planet II,* will treat us to unprecedented footage of our planet's most enigmatic environment. We'll glimpse methane volcanoes erupting in the Gulf of Mexico, plunge into the 1km-deep Antarctic abyss, and meet a menagerie of sealife, including crafty, tool-using tuskfish, the hairy-chested Hoff crab, and giant trevally fish that catch birds in mid-air.

The technology has come a long way since the original 2001 series. This time around, ultra-HD tow cams capture predators head-on, suction cams allow us to ride on the backs of whale sharks and orcas, and low-light cams bring us the magical luminescence of *Noctiluca* 'sea sparkles', dancing to the wing beats of shoaling mobula rays. Could this prove to be *Blue Planet II*'s 'iguana vs snakes' moment?

Giant cuttlefish mating off the coast of South Australia

Bottlenose dolphins surfing in South Africa

5 MORE DATES FOR YOUR DIARIES

1 IN CASE OF EMERGENCY
SCIENCE GALLERY DUBLIN,
13 OCTOBER 2017–4 FEBRUARY 2018

How will it end: with a bang or a whimper? This free exhibition explores our fascination with the apocalypse, looking at the ways the world might end and asking what we can (hopefully) do about them.

2 #OPERAPASSION DAY
19 OCTOBER

As part of this UK-wide celebration of opera, Manchester's Museum of Science and Industry hosts a 'science of opera' live streaming event featuring a series of experiments showcasing the power of the human voice.

3 FIZZ BANG WALLOP: A TUDOR FIREWORK SPECTACULAR
BBC FOUR, **FIRST WEEK OF NOVEMBER**

Historian Lucy Worsley and materials scientist Zoe Laughlin recreate a spectacular firework display designed especially for Queen Elizabeth I, using pyrotechnic science to replicate the original Tudor rockets, fireballs and fire-breathing dragons.

4 XBOX ONE X
RELEASED ON 7 NOVEMBER, £449.99

This high-end version of the Xbox One is set to become the most powerful console on the market. We won't be seeing any exclusive titles, but there'll be plenty of enhanced games for those who crave a 4K gaming experience.

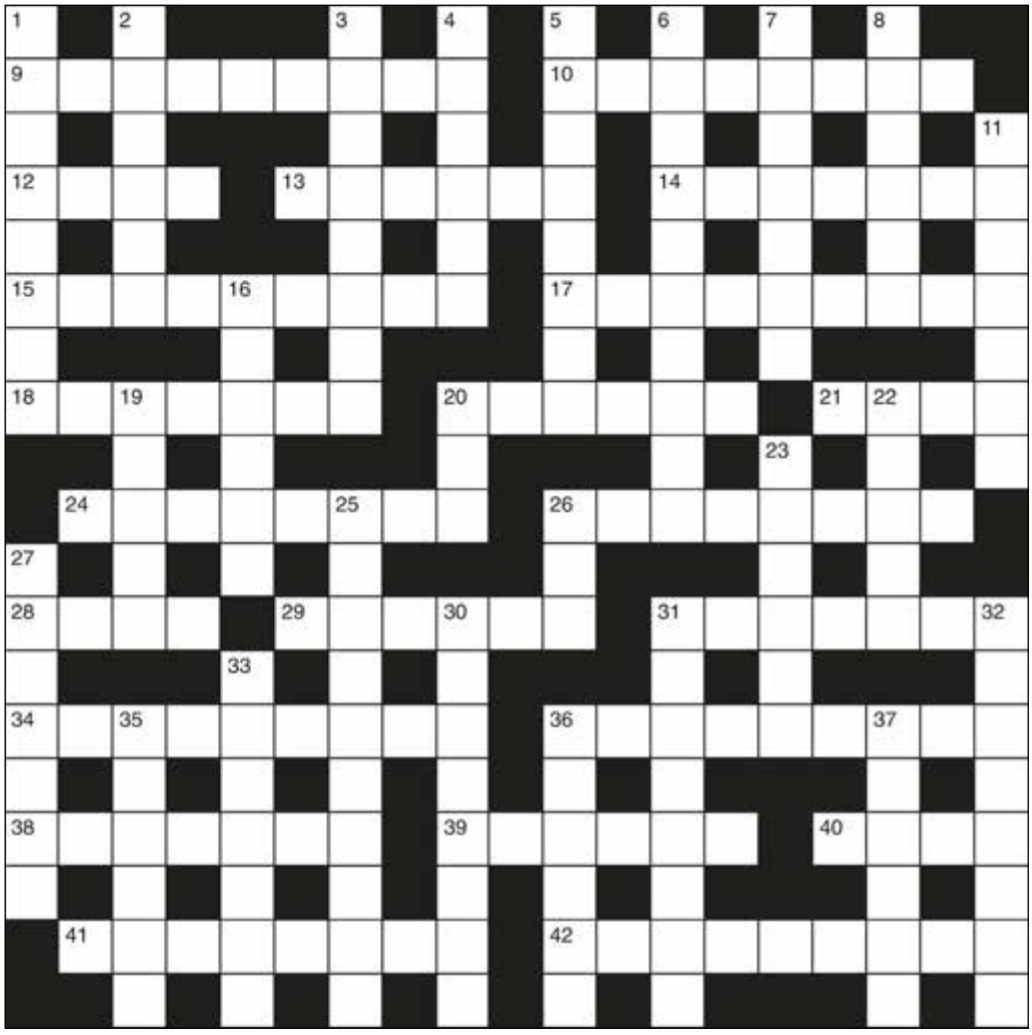
5 MAIL RAIL
THE POSTAL MUSEUM, LONDON, **OPEN EVERY DAY**

Visitors to this recently opened central London museum can now ride the Mail Rail, a miniature railway that once transported London's letters deep underground. Toot toot!

FIND OUT MORE

For more of this month's best events, shows and books, head to bit.ly/BBCFocusBrainFood

BBC FOCUS CROSSWORD
GIVE YOUR BRAIN A WORKOUT



ACROSS

9 Disorderly exit – scene is a way of life (9)
10 Environmental transfer has nothing in tandem (8)
12 Dullard of calibre (4)
13 Sign about a domineering woman (6)
14 About spy being a catalyst (7)
15 Displace a strange, Ancient Greek doctor (9)
17 Ugli variety in old America found in marshes (9)
18 Tear us away to unknown river mouth (7)
20 Enemy volunteers to get left in defensive position (6)
21 About to find honour in stupor (4)
24 Caught by Peter ordering virtual companion (8)
26 Revolutionary claim involving compound (8)
28 Free to wander around coral ridge (4)
29 Ready-made pressure to judge sailor (6)
31 Chap is confused by one Indian game (7)
34 Exploding pulsar for a mineral (9)
36 Dan's sort upset by medium desert wind (9)
38 Bear has opening in ear (7)
39 Mother's character? (6)
40 Appearance is spiteful, by the sound of it (4)
41 Sack everyone with bearing in defence (8)
42 Scientist is at an organisation with Thomas (9)

DOWN

1 Frenchman set off an ember in lining (8)
2 Fool king, in charge of an acid (6)
3 Trendy, if tiny, displaying limitlessness (8)
4 Slow down engineers by throwing dart (6)
5 Total type of zero (8)
6 Work together to get position indicator (10)
7 Many CID characters are energetic (7)
8 Blade twirled round shows ability to shine (6)
11 Concoction is eaten in Greek winds (7)
16 The Spanish have designation for part of tooth (6)
19 Reported occasion for flavouring (5)
20 Overweight fellow at a junction (3)
22 Alright for a Greek character to have an animal (5)
23 Endlessly debate sports equipment (10)
25 Hear ripple put out by printer, say (10)
26 Some bread for a swan (3)
27 Fungus growing on chocolate (7)
30 Boil pelt with relative (8)
31 Criticise scare about a gland (8)
32 Resistance to infection is often diplomatic (8)
33 Weep, having gone off temperature reducer (7)
35 Acceptable to spin guns around one nail (6)
36 Relaxed as van is brought back by guide (6)
37 I would work first on moon – that's addictive (6)

ANSWERS

For the answers, visit **bit.ly/BBCFocusCW** Please be aware the website address is case-sensitive.

Dr Andrew Digby

"This month sees a milestone as we finish sequencing the genetic codes of all living kākāpō"

How did a former astronomer come to care for the world's weirdest parrot? This month, **Helen Pilcher** talks to **Dr Andrew Digby** about career changes and the charismatic kākāpō

Have you always been interested in science?
Always. My mum was a laboratory chemist at a brewer's in Norwich. She encouraged me and my brothers to take an interest in science when we were kids. I loved going to local nature reserves and watching the sky at night. I also recorded the weather every day for seven years: rainfall, temperature, wind speed, that sort of thing. If we went on holiday, I'd get the neighbours to do it so there weren't any gaps in my data.

How did your scientific career begin??
My PhD in astronomy led to a post-doc with NASA. We built an instrument that looks for planets in distant solar systems and deployed it on a US Air Force spy telescope, on a mountain in Hawaii. During the day, they'd use the telescope to snoop on satellites. It was all very secret. Then at night, when I went to use it, I had to be escorted everywhere because I'm not a US citizen. It was a bit crazy, but we did find some candidate planets.

How did you come to work in conservation?
I live and work in New Zealand now. When I first arrived, I got a job doing weather forecast modelling, but also did some voluntary work counting kiwi on the side. That led to a second PhD, studying the bioacoustics of kiwi calls, but I never dreamed I'd end up working with kākāpō.

What is a kākāpō?
Kākāpō are these weird, green, nocturnal, ground-dwelling parrots that are unlike any other bird. They are found only in New Zealand and have nearly 30 million years of unique evolutionary history. They're also incredibly charismatic, but they've been decimated by invasive species so there are only around 150 alive. I'm now the scientific advisor for the national Kākāpō Recovery Program.

What's that like?
It's like the premier league of conservation. Without our help, the species would undoubtedly go extinct. We manage the birds on predator-free islands and do everything we can to help them breed. This month sees a milestone as we finish sequencing the full genetic codes of all living kākāpō and a handful of dead ones too. It's the first time this has ever been done for all members of a species.

Why is it so important to sequence the genomes of all of the kākāpō?
It gives us a whole level of information that we've never had before. We can use this information to shed light on the birds' family tree and problems such as infertility and disease. It's going to be an amazing resource, available to anyone that wants to use it. But the kākāpō is only half of my job.

What's the other half?
I look after another endangered New Zealand bird called the takahē. It looks like a bit like a non-endangered bird called the pukeko, and is often mistaken for it. Its main problem, however, is that it lacks the kakapo's charisma. It's in desperate need of some positive PR. Can you give it a mention, please?

Consider it done.

Dr Andrew Digby is a scientist for the kākāpō and takahē recovery programmes at the New Zealand Department of Conservation.

DISCOVER MORE

To listen to episodes of *The Life Scientific* with top scientists, visit **bit.ly/life_scientific**

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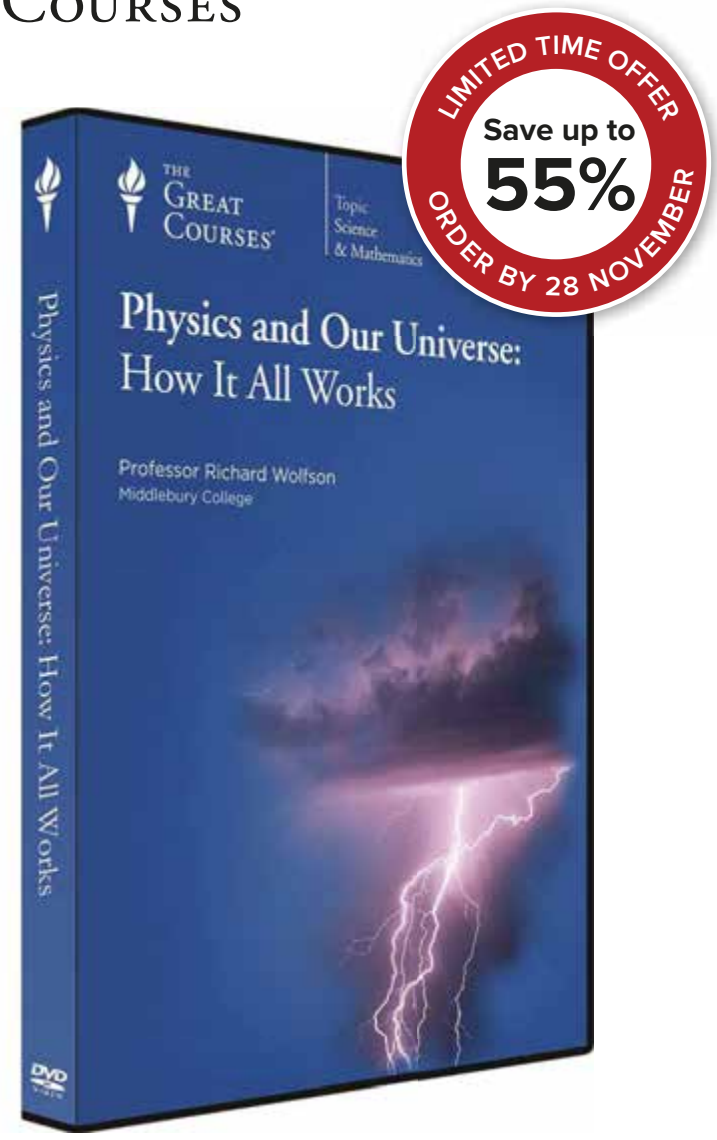

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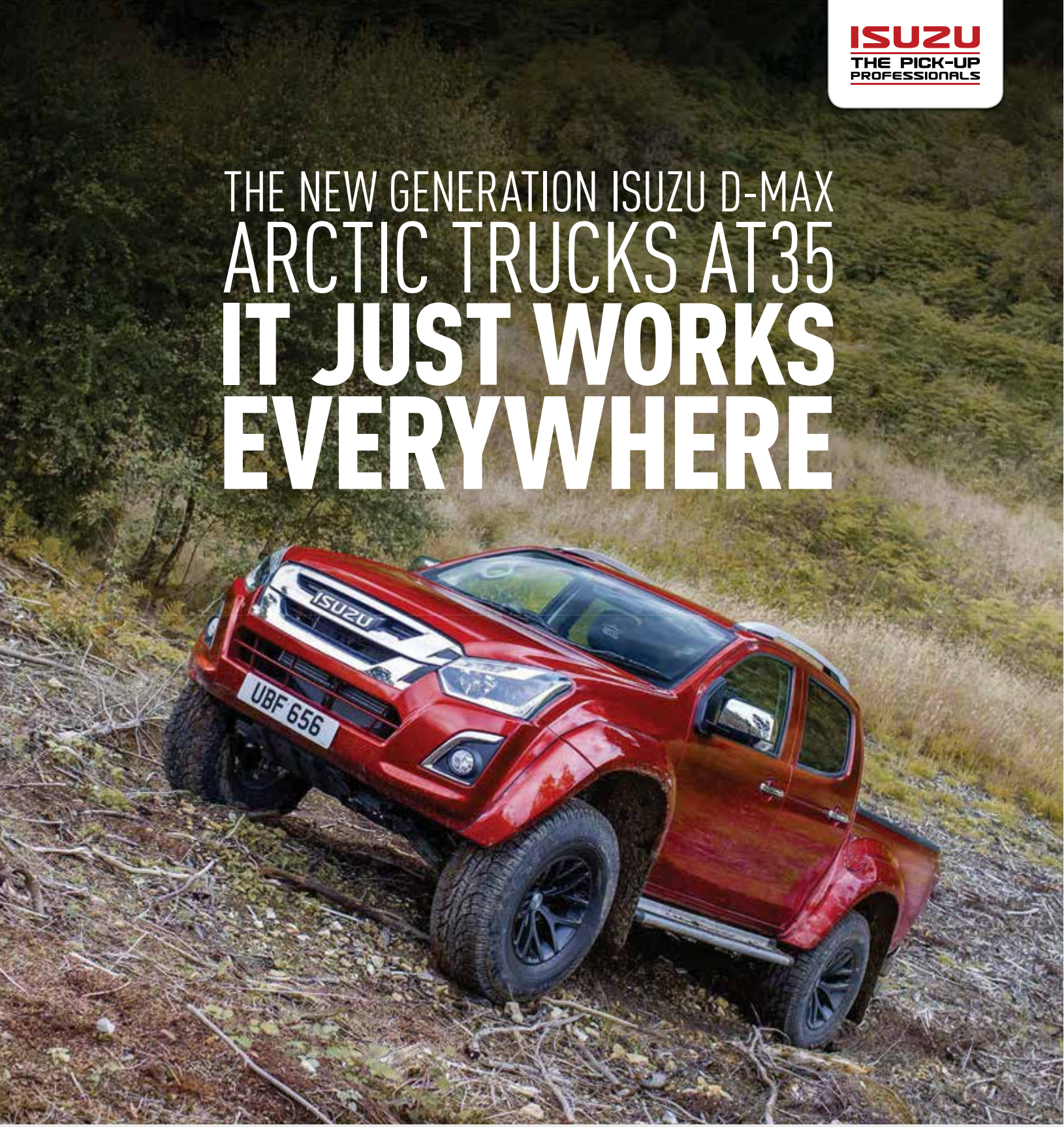

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